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REPORT ON ECHO-SOUNDING AND ASDIC FOR FISHING PURPOSES

EDITED BY
W. C. HODGSON and Á. FRIÐRIKSSON

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PREFACE

AT the annual meeting of the International Council for the Exploration of the Sea, held in Copenhagen in October 1950, the Chairman of the Herring Committee suggested that the time was ripe for collecting together as much information as possible concerning the problems of echo-sounding as an aid to commercial fishing.

At the close of the meeting, the following resolution was proposed and accepted:—

"That the Chairman of the Herring Committee should collect requirements for echo-sounders and Asdic for location of fish shoals, into a document to be made available to manufacturers, who would then be supplied with copies of the requirements and invited to supply further information."

Accordingly, in December 1950 the General Secretary sent out a comprehensive questionnaire to members of the Herring Committee, as a result of which a very fair picture of the state of echo-sounding in the various member countries has been obtained, and further, since the same questionnaire has been sent to the more important fishing countries outside the scope of ICES, it is now possible to present a much wider survey than was originally visualised. The questionnaire ran as follows:—

I. Echo-Sounders.

1. Are echo-sounders in use in your country for the detection of submarine fish shoals?
2. What species of fish (or even whales) are sought for by means of echo-soundings?
3. What gear is used for catching shoals, located by echo-soundings?
4. What year were echo-sounders introduced for fishing purposes in your country?
5. What is the lowest size limit for vessels using echo-sounders now?
6. What (approximate) percentage of decked fishing vessels are now equipped with echo-sounders?
7. What types of echo-sounders are now in use in your country? (Please note the relative importance—number or percentage—of each type).
8. Has there been any trend towards a particular type (or types) of echo-sounders?
9. What improvements on current echo-sounders would you like to propose in order to increase the efficiency of the instrument for fishing purposes (improvements might concern (a) price, (b) size, (c) exactness, (d) strength, and (e) facility in handling).
10. Has it been possible to separate different species of fish, by means of soundings, and, in that case by which type of sounder?

II. Asdic.

1. Is Asdic or other similar instruments (Sonar) in use for fishing purposes in your country?
2. What year was it introduced?
3. How many sets are now available for fishery research?
4. What types and how many of each?
5. How far can your Asdic reach when seeking for fish, and how exact are they?
6. Would you recommend any amendments on the types of Asdic which are now available, and if so, which?

During the annual meeting of 1951 in Amsterdam, a short preliminary survey of the results was given, and the collection of additional material was recommended.

At the annual meeting in Copenhagen in 1953 it was decided to proceed with the preparation and publication of the results of the enquiry, bringing the information up to date where possible, and a small editorial sub-committee was appointed to carry out this work. This Committee included, apart from the General Secretary and the Chairman of the Herring Committee, representatives from Denmark, Germany, Norway, Sweden and the United Kingdom.

The Committee met at Charlottenlund in March 1954 to discuss the replies to the questionnaire and to decide on the general form of the publication, which, it was agreed, should take the form of a general review of present-day knowledge of echo-sounding in relation to the commercial fisheries.

The replies showed that Asdics are only used in Whaling and have as yet no place in other commercial fisheries although horizontal echo-sounding has recently been introduced to the Norwegian herring fishery.

It is with the agreement of the Committee that we present the following symposium on echo-sounding as an aid to fishing.

W. C. Hodgson,
Chairman, Herring Committee.

Arni Friðriksson,
General Secretary.

Historical Narrative

TO trace the history of echo-sounding development from the early work of MAURY in the 1850's to the precision instruments of today would be a difficult task, and it is no less difficult to produce an accurate account of the events which led to the application of the technique to fishery research.

Long before echo-sounding in fisheries became a reality there were hints and suggestions of the shape of things to come, and one suggestion which must be given high priority came from Professor PORTIER in an address on the "Application of Supersonic Waves to Biological Oceanographical Research" to the Biological Society in Paris in 1924. Here, PORTIER said: "Il semble bien que les bancs denses des poissons comme la Sardine ou le Hareng peuvent réfléchir les ondes ultra-sonores, et qu'on pourra, par ce moyen, déterminer exactement la profondeur à laquelle se tiennent ces essaims de poissons sur le plateau continental préalablement sondé." Here, indeed, was an idea which was, in 1924, something akin to a prophesy.

In 1926, the French navigator R. RALLIER DU BATY, while on a trip to Newfoundland, noted that the sounder in his ship was giving abnormal signals which he attributed to a shoal of cod, and again, in 1928, similar phenomena, observed on board a Boulogne drifter, were associated with shoals of herrings.

What was probably the first actual experiment with echo-sounding on fish took place in Japan in 1929, when Dr. KIMURA attempted to detect fish shoals by acoustic methods. He used ultra-sonic sound of 200 kc. modulated with a sonorous wave of 1 kc. The high-frequency waves which were transmitted in the water by quartz projectors were reflected and absorbed by the fish bodies which were in the path of the sound beam, and were reflected and refracted by the turbulence of the water due to the movement of the fish. KIMURA was able to detect fish groups by studying the change in the sound picked up by another quartz receiver, and he was successful in detecting 50—80 % of the shoals of fish in the ponds used in the experiments.

In April, 1933, H.M.S. "Challenger" reported a strange occurrence off Start Point on the south-west English coast. While using her Deep Sea Echo Gear in 40 fm. and on an even bottom, some consternation was caused when very rapid shoaling to 5 fm. was observed. The engines were put astern and 40 fm. was again recorded. A buoy was dropped to enable investigations to be made, and once again, 5 fm. was shown on the sounder. It was concluded that the sounder had detected a dense shoal of fish which was temporarily dispersed by the noise of the engines when they were put astern.

Sir JOHN EDGELL, Hydrographer to the Royal Navy at the time of this occurrence, mentioned this report in the Hydrographic Review of Monaco in 1935 and at the same time showed drawings of the echo-traces obtained by H.M.S. "Challenger". These are almost identical with traces made by research ships of the Ministry of Agriculture and Fisheries of England, thirteen or more years later, when it was established that dense shoals of pilchards were to be found off Start Point during the summer.

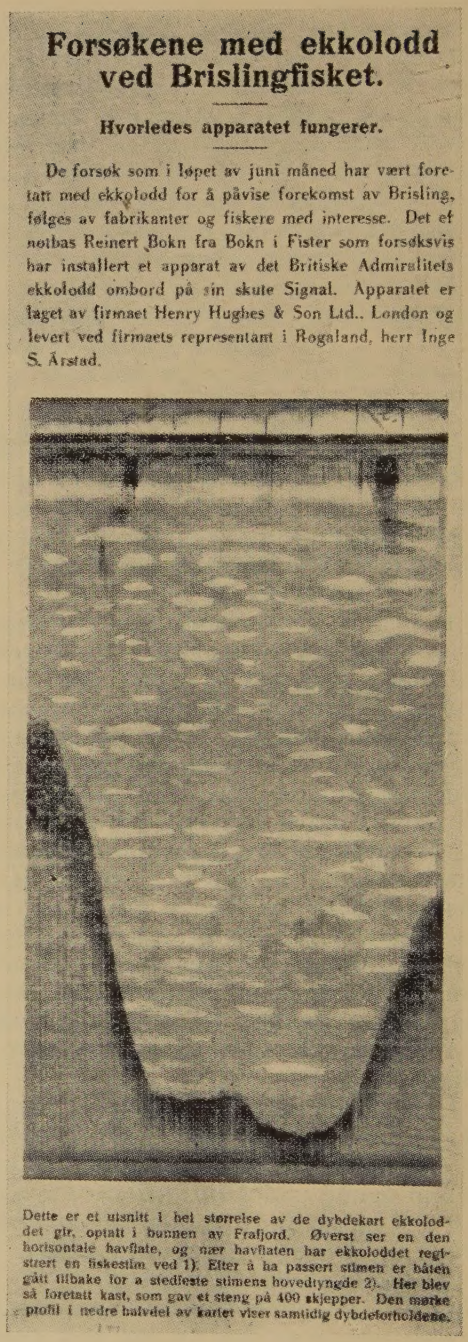
In 1933, one of the first attempts to couple fishery research with echo-sounder observations was made off the English north-east coast by HODGSON and BALLS, the former operating a Marconi 424 visual sounder in the research ship "Onaway", and the latter a similar sounder in his own commercial herring drifter "Violet and Rose" of Great Yarmouth. HODGSON noticed that "false" echoes occurred at certain

depths at night and these he associated with herring shoals. He then attempted to correlate the frequency of these echoes with the catches of the various drifters, but there were so many difficulties that no definite results were obtained. Skipper BALLS, however, was more fortunate, for he correlated the frequency of echoes *with his own catches*, and thereby began a wonderful series of observations which were ultimately published in 1946, and which firmly established him as a pioneer in the field of applied echo-sounding.

The visual machines increased in popularity in the fishing fleets, but mainly as navigational aids, and it can safely be said that real progress in the application of sounding to fisheries began with the introduction of the recording instrument, and in this connexion, too high praise cannot be accorded to Dr. A. B. WOOD of the British Admiralty Scientific Service.

In 1929, Dr. WOOD began experimenting on magnetostrictive transmitters as an alternative to the piezo-electric system developed by Professor LANGEVIN and M. CHILOWSKY, which was used extensively in French and English sounders. The previous sounders used by the British Admiralty were of the low-frequency (sonic) type, and in February 1930 the first sea trials with the entirely new high-frequency sounder with paper recorder were carried out at Sheerness. After this sounder had been covered by British patents, Messrs. Henry Hughes and Sons secured the contract to manufacture the instrument, and one of the early Hughes models was eventually installed in the steam trawler "Glen Kidston" which made an experimental voyage from the Humber to Bergen in 1933. On this historic trip, a continous record of the sea-bed was produced for the first time, and a fishing skipper was now able to study the course of the sea bottom without having to rely on past impressions of a moving light.

It has long been accepted that when OSCAR SUND used this new magnetostriction type of recorder in the Norwegian research ship "Johan Hjort" in 1935 he was making echo-sounding history by being the first to publish a recording of cod. This he did in the English publication "Nature" in June 1935. It has now been discovered that SUND was forestalled by another Norwegian, a fishing skipper named REINERT BOKN who installed one of the newly introduced Hughes "Admiralty" type sounders in his ship "Signal".



Forsøkene med ekkolodd ved Brislingfisket.

Hvorledes apparatet fungerer.

De forsøk som i løpet av juni måned har vært foretatt med ekkolodd for å påvise forekomst av Brisling, følges av fabrikanter og fiskere med interesse. Det ef notbas Reinert Bokn fra Bokn i Fister som forsøksvis har installert et apparat av det Britiske Admiralitets ekkolodd ombord på sin skute Signal. Apparatet er laget av firmaet Henry Hughes & Son Ltd.. London og levert ved firmaets representant i Rogaland, herr Inge S. Årstad.

Dette er et utsnitt i hel størrelse av de dybdekart ekkoloddet gir, optatt i bunnen av Frafjord. Øverst ser en den horisontale havflate, og nær havflaten har ekkoloddet registrert en fiskestim ved 1). Etter å ha passert stimen er båten gått tilbake for a stedfeste stimens hovedtyngde 2). Her blev så foretatt kast, som gav et steng på 400 skjepper. Den mørke profil i nedre halvdel av kartet viser samtidig dybdeforholdene.

Figure 1.

This is believed to be the first published echo-chart showing the presence of fish. It shows the sea-bed and the shoals of sprats near the surface. The chart was produced by REINERT BOKN in Norway in June 1934, the sounder being of the British Admiralty pattern made by Henry Hughes & Sons, London.

Skipper Bokn succeeded in obtaining a fine recording of sprats near the surface of the water in Frafjord, and as a result, he caught about 68 hl. of fish. This truly historic record was published in the Stavanger periodical "Tidsskrift for Hermetikindustri" in July 1934, eleven months before Sund's record appeared.

In 1937, Runnström used the recorder to survey the fishing grounds and plot the distribution of the herring shoals along the Norwegian coast west of Haugesund, and Tester, in 1942, using a "Husun" MS 111 recorder in the motor vessel "Nishga", located herring shoals in the Vancouver district and showed that the ultra-sonic method of detection had obvious advantages over the old method of using the feeling wire.

Hodgson and Richardson, while working on the pilchard shoals of the western English Channel, showed that the sounder could be used in setting the ring-net and also suggested various ways of keeping in contact with the shoals while the net was being shot.

In 1946, Renou and Tchernia, in the French escort vessel "Le Grenadier", carried out experiments with Sonar (Asdic) and a recording echo-sounder and succeeded in locating shoals of sprats, herrings, pilchards, and tunny off Brittany and in the English Channel. Apart from pointing out that they had found three types of trace, all of which could be associated with herrings, they came to no definite conclusions about the traces produced by the different species. Hodgson, in 1950, however, showed for the first time that one could discriminate between different species, since the traces produced by herrings were different from those produced by pilchards, and both of these were different from traces produced by gadoid fishes.

In the years following the second World War, the echo-sounder became widely used in world fisheries and new applications of the sounding technique were rapidly being devised.

Cushing, for example, first used a new form of echo-survey in 1949. He arranged his cruise grid to cover an area of sea larger than that in which the herring fleet was operating, and on the line of stations he used the sounder continuously. He analysed the patches of pelagic fish by counting the number of individual traces (or stylus marks) which made up the soundings on the recording paper, and by assuming a linear relationship between the number of traces and the amount of fish, he produced a chart showing the distribution of pelagic fish in the area.

This system was used successfully to chart the distribution of pilchards in the English Channel in summer, when the presence of pilchards as shown by the echo-survey, was confirmed by the distribution of the pilchard eggs as sampled by the research ship.

Krefft and Schüler surveyed the northern part of the North Sea, using the depth of trace to assess the abundance of fish, and Richardson, Parrish and Craig used surveys to identify both sprat and herring shoals.

Another important development has been the use of the sounder to help in the study of fish behaviour, such as the reaction of pelagic fish to lights of various kinds (Hodgson, Richardson, Craig, Schüler, and Krefft), and also to observe diurnal migrations (Runnström, Tester, Schüler, Balls, and Richardson) and its use in the study of the operation of fishing gear has not been neglected. In this connexion, Wood and Parrish have reported on the use of the sounder in determining the height of the head-rope of the otter trawl and also the extent of the gape of a pelagic trawl, and the distance of the net from the sea-bed. This is an important development which, it is hoped will ultimately lead to a system of remote control by which a fishing skipper in his wheelhouse will be able to set his midwater trawl to his liking and to watch its subsequent behaviour.

It will be seen from this account of the history of echo-sounding as an aid to fishing, that, like the evolution of the sounder itself, the application of the technique is being developed and extended by workers from many different countries, and it may be that future international contributions to the study of echo-sounding and fishing will lead to still further advancement of a science which, after all, is but a few years old.

The Principles of Echo-Sounding

PRESSURE waves, or sound waves, in water are propagated with constant velocity, and can be reflected by obstacles in their path. This is the fact on which echo-sounding depends, for the echo of a transmitted sound can be picked up and, after suitable amplification, can be made to operate some kind of indicator. Echo-sounding equipment therefore consists of a sound transmitter, a receiver, an amplifier, and an indicator or recorder.

Sound Velocity.

The velocity of sound is independent of frequency, but varies slightly with the temperature and salinity of the water, and with pressure, the corrections for these factors being generally less than 2%. The actual sound velocity is about 1,500 metres/sec. (4,920 feet per second).

Attenuation and Diffraction Effects.

There is a loss of energy from the transmitted sound wave during its passage through the water, and this attenuation increases as the frequency is increased, and thus low frequencies (2 to 10 kilocycles) are used for sounding in the deep waters of the ocean.

There may also be diffraction effects. Since the sea often shows stratification of temperature and salinity, so also there may be stratification of the sounding velocity. When this occurs, the sound waves follow a curved path due to diffraction, instead of being straight lines.

Determination of Distance.

The constant velocity gives a linear relation between the distance travelled by the sound, and the time interval. This makes it possible to measure distance by measuring the time elapsed between a transmission and the arrival of the reflected sound. The echo range (R) is half the product of time and velocity ($R = {}^1/_2tV$), the accuracy of the determination depending on the accuracy with which the velocity is known, and the exactness of the time measurement. To reach an accuracy of $\pm$ 0.15 metres (6 inches) it is necessary to measure the time within about $\pm$0.0002 seconds.

For the purposes both of navigation and fishing we require the true depth, i.e., the *vertical* distance from the sea-bed or fish shoal to the sea surface. The echo-sounder provides a measure of the range, or distance, *in a direct line* from the ship to the target. The "echo distance" and the true depth coincide only if the reflecting objects are located vertically beneath the ship, which does not always happen. If the sound beam is a wide one, the error may be considerable since echoes can be received from an object well away to one side or the other.

For all objects suspended in the water, the echo distance will be greater than their true depth. On the other hand, the indicated depth of the sea-bed may be less than the true depth, if the ship is approaching a slope. Hence the bottom topography is recorded as more smooth than it really is, and a narrow channel is hidden by the echoes from its sides. For some purposes it is therefore convenient to speak of "echo distance" rather than depth.

The errors discussed here decrease with reduction in the sound beam angle. This angle is a function of the diameter D of the transmitting and receiving oscillators, and of the frequency. In order to obtain a narrow beam, the diameter has to be several times larger than the wavelength of the sound. At a frequency of 3 kc./s. the sound wavelength is 0.5 m. and it is not convenient to make directional oscillators, on account of their bulk and cost. On the other hand, at 30 kc./s. the wavelength being only 5 cm., this can readily be done. This is one of the reasons why frequencies of the order of 20 to

50 kc./s. are normally used for echo-sounding, except for work in oceanic depths.

Several factors control the form and extent of the zone searched by an echo-sounder. The sound energy is highest in the centre of the beam, i.e., perpendicular to the face of the oscillator. At increasing angles from this perpendicular, the energy decreases, and it becomes zero at an angle α given by $\sin \alpha = \frac{1.2\lambda}{D}$, where λ is the wavelength of the sound in water. The path of the sound rays is affected by any stratification of the sounding velocity, and the effective range is reduced by attenuation in the water. Hence the received energy depends on these factors and also, of course, on the reflecting properties of the target and the degree of amplification used in the receiver.

Choice of Beam Angle.

The zone searched by an echo-sounder is of a pear shape, rather than a cone as is usually assumed. The size of this zone can alter with changes in any of the factors mentioned above. It follows that with a given machine, the strength of the echo may vary with hydrographic conditions and with the reflecting power of the sea-bed or other target. Use of a narrow sound beam allows accurate recording of the bottom topography, and precise determination of the size and vertical extension of shoals of fish. However, for fishing, a wide beam is to be preferred which gives increased searching power by allowing the detection of shoals on either side of the ship's track. Another disadvantage of a narrow beam is that in rough weather, the oscillators may swing appreciably in the time between transmission and return of the echo, and soundings may thus be lost. Hence choice of beam angle must be a compromise between conflicting demands, and the decision must depend on the importance of each to the purpose in mind. It would be possible to meet the needs of varying applications by using several sets of oscillators, each providing a different beam angle. A change-over switch would allow the most suitable oscillators to be selected according to conditions. The effect of the ship's rolling could be eliminated by stabilizing the oscillators by means of a gyroscopic suspension, or by a device which allows transmission only when the ship is upright. These solutions are likely to be too expensive for commercial use.

Choice of Frequency.

Here again, compromise is necessary. On one hand, we require a suitable beam angle, short pulse length, short wavelength and a convenient installation, and on the other hand we require also an adequate depth range, and a strong echo, which latter often depends on the size of the objects we are searching for. On the whole, for oceanic soundings to, say, 10,000 metres, low frequencies from 2 to 10 kc./s. have to be used, while for fish detection 20 to 50 kc./s. seems to be the most suitable frequency. Machines are also used on 80kc./s. for precision measurements in shallow water.

Apart from the narrow beam, and the low cost of the oscillators, high frequency has another advantage. The pulse length can be made extremely short, and this gives good resolution, i.e., separation of echoes from targets at ranges which differ only slightly. This is required for the detection of fish near the bottom, and makes estimation of the density of shoals easier.

Acoustic Reflection.

Reflections occur at the surface of bodies whose sound-transmitting properties are different from those of the medium of propagation. Reflecting obstacles may be rock, sand or clay on the sea-bed, or objects suspended in the water such as fish, planktonic organisms or air bubbles. Extreme temperature gradients or salinity stratification also give rise to sound reflections, and may cause interference, particularly when horizontal sounding is attempted.

The acoustic impedance I is the product of sound velocity and density for the medium concerned, ($I = Cp$) and the reflection factor depends on the size to wavelength relationship (λ/d relationship), and the shape of the reflecting body, and on the *difference* in acoustic impedance between the water and the reflecting body, i.e., the reflected amplitude is proportional to $(I_1 - I_2)/(I_1 + I_2)$. Rocks and air bubbles are good reflectors in water, whereas such materials as rubber or plexiglass give relatively weak echoes. If the reflecting body is free to oscillate, reverberation occurs and the body becomes a sound transmitter (i.e., we can regard it as a secondary source). In the case when the resonant frequency of the body is the same as the sound used, then very strong echoes will be obtained. If the reflecting particles are very small compared with the wavelength, the scattered wave is sent out uniformly in all

directions. If the obstacle is very large compared to the wavelength, reflection occurs only from the surfaces irradiated by the transmission, and a clear-cut sound shadow is formed behind. When the size of the reflector is almost the same as the wavelength, a variety of interference phenomena can occur. Plane surfaces perpendicular to the beam give the best reflections, whereas the reflected sound is dispersed by rounded surfaces. On the other hand the latter give rise to an echo, no matter what their orientation. When several reflecting bodies are at the same echo distance, echoes from them are received simultaneously. The echoes are thus superposed and the strength increased. It follows that the shape and density of the fish shoal influences the strength of the received echo.

Production of Sound Pulses.

This is usually done by the transformation of an electrical oscillation to a mechanical one, making use of either the piezo-electric, or the magnetostriction effect. Similarly the received echo, consisting of very weak sound pulses, is transformed to electrical oscillations again. Magnetostriction oscillators are, in general, preferred, as being cheaper and more robust in construction.

The transmitted pulse may consist of damped or undamped oscillations. In the latter case the oscillations are of nearly constant amplitude throughout the transmission period, in the former the amplitude dies away exponentially from a maximum which can be made of high energy and very short duration. Thus the resolving power is higher. Undamped oscillations provide a longer pulse and allow us to distinguish reverberation from true surface reflection, by noting the difference between the lengths of the received and transmitted pulses.

Receiving and Display Equipment.

The electrical output from the receiving oscillator has to be amplified, and this is done by a pulse amplifier of two or more stages, to provide an output suitable for a recorder or indicator. This measures the time elapsed between transmission and echo, by means of some device moving at an accurately controlled speed so as to convert the time interval to a distance. The relationship between this distance and the actual depth depends on the relation between the controlled speed, and the velocity of sound in water. *Indicators* generally provide the depth by means of a rotating disc which is illuminated by a flash tube at the moment the echo is received, or by using the echo signal to deflect a rotating mirror. This deflection makes a spot of light deviate from its otherwise straight path.

In a *recorder*, a stylus pen is moved at constant speed over a recording paper on which a mark appears whenever the voltage on the pen exceeds a critical value. The recording paper can be of electrolytic type or of the carbon type. The first named, also known as wet paper, is impregnated with iodide solution and starch, and iodine is liberated by electrolysis, giving a dark spot to mark the echo.

The carbon, or dry paper, is coated with a white layer which is burned away by an electric spark, exposing a dark under-layer of graphite.

Another method of display is to use a cathode-ray tube. The received signal gives a deflection perpendicular to the time-base. Very high time-base velocities can be used, giving extremely high resolution. This method gives a good measure of the echo amplitude, since this is proportional to the deflection. The drawback is the same as for any indicator, that each successive indication has to be watched, and there is no permanent record of the "pattern" of successive echoes as with a recorder. By combining a cathode-ray tube with a recorder, the advantages of both methods can be enjoyed, and a number of combination machines are already being manufactured in different countries.

Identification of Echo-Traces

THE appearance of fish echoes on a recording sounder shows such variations in type as to suggest the possibility of identifying the fish concerned from the character of the trace. It will be clear, however, that differences in shoaling behaviour, in the distribution of fish in the sea, are the causes of the differences in echo patterns upon the paper. Scientific knowledge of the shoaling habits of various species of fish at different times of the day and of the year, and in varying environmental conditions is so far from complete that it is impossible to write down any certain rules of identification.

There is, of course, a great deal of negative information. We do not, for instance, expect to find haddock swimming in compact shoals in midwater, but if we consider those fish which are known to shoal, and to frequent the mid and upper water at times, for example, herrings, pilchards, sprats, whiting, cod, sandeels, and species of mackerel and add to this list dogfish, saithe and probably others, we find that these can at various times adopt a variety of shoaling habits and can produce almost the entire range of echo types.

First let us consider the compact shoal, that is to say, a shoal whose dimensions are small compared with its distance from the ship. Such a shoal produces the familiar "comet" or "plume" trace, and as the dimensions of the shoal increase there is a transition to flat topped masses (Figure 1, top), which are characteristic of heavy herring or pilchard concentrations in certain areas.

Widespread distribution of fish at or around a particular depth give rise to a trace which we may describe as a "layer". This may be either of homogeneous appearance (Figure 1, centre and bottom), or may be broken up into separate half moons, plumes or spots. The difference between half moons and plumes is largely determined by the speed of the ship, and this breaking up of a homogeneous trace is clearly the result of either, (a) the arrangement of the fish in groups or little shoals, or (b) the fact that individuals are being separately recorded by the sounder. As the width of the effective sound beam varies with the depth, the appearance of the echo-trace from a given geometrical arrangement of fish may be different at different depths. The probability of individuals being separately recorded is greater when the fish are in the uppermost water layers. The presence of a "spotty trace" is a clear indication that we are dealing with individual fish whose reflecting power is only great enough for them to give an echo when they are in the centre of the sound beam.

The reflecting power of particular fish varies considerably with the frequency of the echo-sounder used, but in general larger fish tend to give stronger echoes than smaller fish, and fish with swim bladders to give stronger echoes than those without.

Identification Experiments.

While we have said that no general rules can be given for identification, yet by patient and careful study of particular areas at particular seasons a detailed knowledge of the fish populations and their appearance on the echo-sounder can lead to greater confidence, and sometimes practical certainty, in interpretation of some traces. Any observant fisherman will find opportunity for study of the commercial species in this way, while a research vessel with its power to capture organisms of more diverse kinds is usually able to add something about the other populations. Sampling by net or fishing line, or investigation by explosive charges or underwater cameras, and the use of plankton nets and young-fish-trawls are among the methods which have been applied for this purpose. A variation in this method of direct

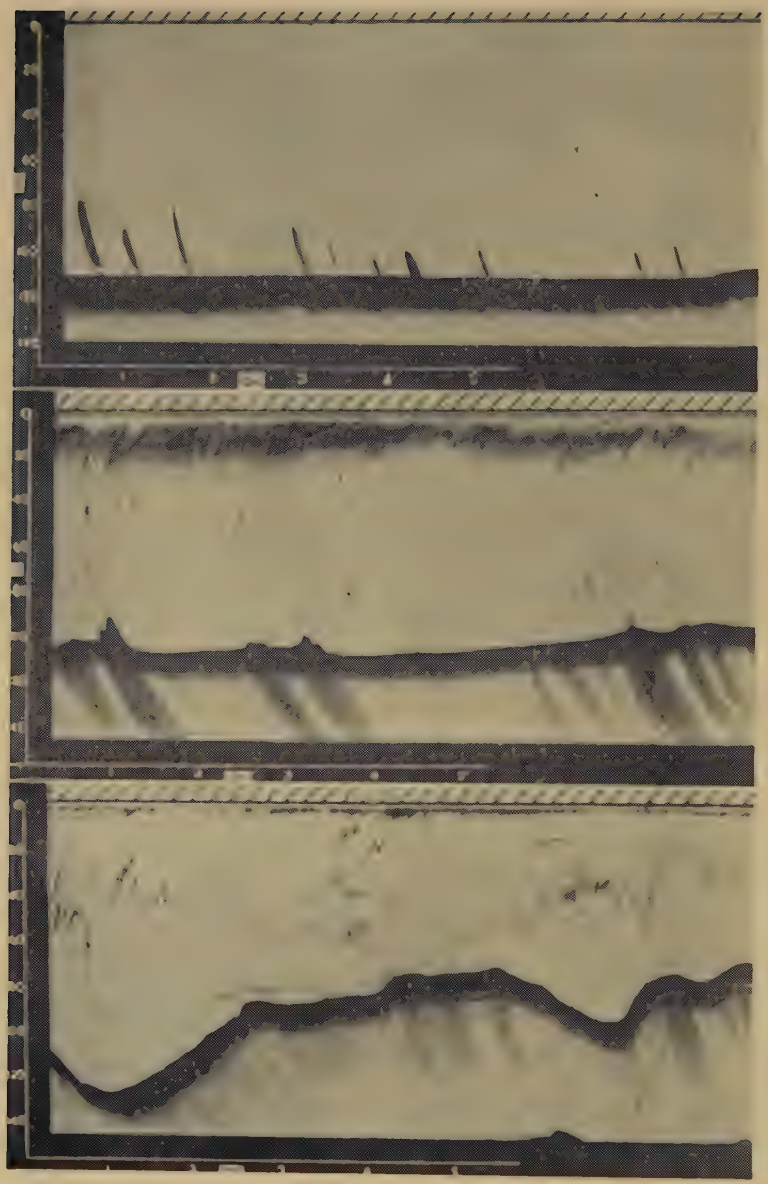


Figure 1.

Top.

Characteristic plume traces caused by dense compact shoals of fish. These are herring, 50 miles NE. of Fraserburgh, July, 0400. Echo-sounder, Hughes MS 20, speed of ship 8 knots.

Centre.

Scattering layer due to small organisms at 5 to 15 metres depth, and small plume traces due to small shoals of fish. 5 miles NE. of Noss Head, Shetland in July. Time 1400. Echo-sounder, Hughes MS 20, speed of ship 8 knots.

Bottom.

Spotty trace due to very small shoals, or individual fish, with a homogeneous layer at 90 metres. 20 miles north of Banff, Scotland, in July. Time 1900. Echo-sounder, Hughes MS 20, speed of ship 8 knots.

sampling is the carrying out of echo-surveys of important areas, and comparison of the echo-traces with the results of commercial fishing by a whole fleet of vessels. Further description of these methods is to be found elsewhere in this review. It cannot be too strongly emphasized that it is only after painstaking work in the areas of interest that really useful and meaningful interpretation can be made of echo-survey results. There is no substitute for detailed biological knowledge and fishing experience.

Quantitative Physical Investigations.

It is, of course, the aim of fishery scientists to reduce as far as possible the uncertainties of interpretation. For this purpose it would be helpful to be able to determine some characteristic, such as the size, of the fish producing the echo and to give some estimate of the numbers of fish involved. Size is not, at present, likely to be directly measurable, whereas there is some hope that other helpful measures may be found. These are, firstly, the reflecting power at a given frequency, secondly, the ratio between reflecting power at two or more frequencies and, thirdly, the frequency giving the maximum reflecting power. The first of these methods requires us to isolate a particular echo as due to a single fish, and it is not of itself likely to be of use in identification. The other two methods, however, if they can be made to work at all, will presumably be applicable to echoes from shoals of fish, and clearly give hope of determining the nature of the individual fish, and hence (via method one) their numbers.

It must be remembered that variability in size of fish in a shoal may turn out to provide an insurmountable difficulty to the application of such methods. A very ingenious investigation has been made which illustrates the application of the last-mentioned type of experiment. This was a study of the resonant frequency of organisms forming a deep scattering layer in the ocean. Echoes from an *explosion* were recorded and subjected to harmonic analysis. It was shown that, when the layer migrated vertically, there was a component of the scatterers whose resonant frequency alters. The alteration in this frequency was consistent with the supposition that this component of the scattering was due to the swim bladders of fish.

The Applications of Echo-Sounding

THE echo-sounder was first developed as an aid to navigation, and its initial success as such undoubtedly paved the way for the rapid growth of the echo-sounder industry and the development of the many types of machine available today. This use still ranks as the most important to which the echo-sounder is put, and almost all present-day sea-going vessels, and many which travel on inland waters, are equipped with echo-sounders. Its uses as an aid to navigation vary greatly; fishermen use it in locating and recognizing fishing banks, deep-sea navigators use it as a guide to position on long distance sea crossings, and it is used by all classes of vessels in navigating over unfamiliar routes and in harbour approaches.

The second major use to which echo-sounders are now put is fish location. This use has grown in importance since the second World War, and today the echo-sounder is regarded as an indispensable tool for the pelagic fisherman.

The application of echo-sounding in fish searching grew from chance observations made in the 1930's by fishermen and scientists, notably by BALLS in England and BOKN and SUND in Norway. Their recognition and subsequent investigation of "false bottom" echoes over the North Sea and Norwegian coast fishing grounds led to the now widespread application of echo-sounders for finding and locating fish. This application is of greatest importance and value in the world's pelagic fisheries, particularly for herring, but it has a growing use in the demersal fisheries also.

Many models of echo-sounders are now marketed primarily as fish finders, and much of the current work in echo-sounder development is directed towards improving their efficiency as such. Particular items of study include:—

(1) Transmission frequency.
(2) Method of presentation.
(3) Horizontal search.

Progress in this work has already led to the development of machines operating over a wide range of transmission frequencies, and with different methods of presenting the records. The recent introduction of "combination" sounders, incorporating C.R.T. and paper recorders together, has assisted greatly in the identification of fish near the sea-bed. "Horizontal" echo-sounders are now marketed in some countries, and already this method of operation is proving of great value in the pelagic fisheries in some areas. Further developments along these lines will undoubtedly increase the efficiency of the echo-sounder as a search tool.

The two basic properties of the echo-sounder —depth recording and fish location—has led to its widespread use in oceanographic and fishery research. Among its many uses in these fields, the following are of particular importance.

1. Depth surveying. The greater speed of operation of the echo-sounder over other depth-recording techniques has led to much more detailed knowledge of the contour and nature of the sea-bed, both over the regular shipping lines and in poorly charted areas. The echo-sounder is a fundamental tool in all depth-survey work at the present time.

2. Pelagic fish surveys. Fisheries biologists now use the echo-sounder as a means for studying the distribution and abundance of pelagic fish shoals over wide areas. This technique has had wide application in herring research in European waters, but other species, including pilchard, sardine, tuna, sprat, and cod are being investigated in the same manner.

3. Fish behaviour studies. The echo-sounder has assisted greatly in studying the behaviour of fish shoals in the field. Some examples of such studies, in which the echo-sounder has been and is being used, are as follows:—

(a) The effects on distribution and behaviour of artificial stimuli, e.g., light and sound.

(b) Diurnal vertical migration studies.

(c) The influence of environmental factors e.g., discontinuity layers, on distribution and behaviour.

(d) Reactions of fish to the approach of fishing gear.

4. Performance of fishing gear. The discovery that echoes are returned from warps, otter boards and nets, has led to the now widespread use of the echo-sounder in determining the shape and dimensions of various types of gear during fishing operations. The relationships between the depth at which pelagic trawls operate at different towing speeds and warp lengths have been determined by this means, and measurements have been made of important trawl dimensions such as the vertical distance between headline and footrope of both pelagic and bottom trawls.

In addition to these uses to which the echo-sounder is now put in oceanographic and fishery research, it is also providing important information on organic productivity in the sea. An early discovery, following the widespread use of the echo-sounder on oceanic surveys was the presence in the oceans of "deep scattering layers" which were recorded over long distances and which exhibited marked diurnal vertical movements. The composition of these layers is still a subject of active research in which the echo-sounder continues to play an important role. They are undoubtedly organic in nature, and their study is already providing information on productivity in different areas. Scattering layers are also a common feature of the echo-charts taken over the shallower depths on the Continental Shelf. These are also the subject of active research at the present time, but results have already shown that they are mainly planktonic in origin and that their study may lead to important information on plankton production and distribution in these areas.

It is clear from this short review that the echo-sounder is now an indispensable tool in marine research, and it is likely that its uses will grow in number and importance as developments in echo-sounder design proceed.

The State of Echo-Sounding in Various Countries

Belgium

BEFORE 1949, only those vessels which were employed in coastal fishing were fitted with echo-sounders and these were mainly used for navigation.

It was during the winter of 1948—49 that some Belgian fishermen began to use sounders to help them find the shoals of spent herrings near the coast, and in the following winter the use of sounders was extended to the sprat fishery. Since then, the number of vessels equipped with sounders has continually increased, and by 1951, 31% of the fleet were using sounders.

At the beginning of 1954 the percentage was 46 — 188 fishing vessels out of a total of 410 carrying one or two echo-sounders.

All types are used — recorders, combined optical and recorders, fischlupe and optical— and the following makes are employed: Kelvin-Hughes 82.4%, Elac 9.1, Scam 6.0, Behm 2.0, and Atlas 0.5%.

Denmark

Since the first echo-sounder was fitted in a Danish fishing cutter in 1945 a very pronounced increase has occurred in the number of fishing vessels equipped with sounders.

The first echo-sounder was of the usual indicator type, but the advantages of the recording type soon became evident specially in the trawl fisheries, as this type of echo-sounder yielded valuable information about the character of the bottom.

The purchase of echo-sounders increased greatly following the development of the great pelagic herring fisheries from about 1949 and here a new property of the echo-sounder became essential: its ability to give direct indication of the presence of fish shoals. This property has since been emphasized both by the fishermen using the floating trawl and by those who are fishing with herring bottom trawls.

On 1. January 1953 the situation was as follows: about 470 fishing vessels or about 36% of all Danish fishing vessels over 15 brutto tons (approx. 36 ft. or 11 m.) were equipped with echo-sounders. Of these about 90% were of the recording type, one was of the cathode-ray type and the remainder were of the usual indicator type. The different makes of sounders were distributed in the following way: Atlas 156, Kelvin-Hughes 125, Bendix 116, Behm 45, Radiac (Danish, liquidated 1951) abt. 20, Scam 8, Elac (fischlupe) 1.

There has been a trend from the indicator type to the recording type and also a trend from low frequency (14 kc./s.) sounders towards higher frequencies (30-50 kc./s.).

Some possible improvements in the echo-sounding equipment often emphasized by fishermen, can be stated as follows: lower price and more sturdy construction, lower current consumption, smaller space requirements, and a better possibility of distinguishing fish near bottom.

The cathode-ray instruments will possibly help to meet the last wish. A combination of the cathode-ray and recording type will, no doubt, prove advantageous.

In Denmark no Asdic is in use from fishing or research vessels. A fishery inspection vessel has since 1952 occasionally located herring shoals for the fishermen by means of Sonar.

In the Faroes, the number of echo-sounders was greatly increased when the important herring drift-net fishery north of the Faroes developed. In the beginning of 1954, 70 fishing vessels or about 30% of all vessels greater than 20 tons were supplied with sounders and of these, about 6 are of the cathode-ray type and nearly all the others are of the recording type.

France

In France, echo-sounders are used in the fisheries for herring, cod, mackerel, and sardine, in connexion with trawls, drift-nets and ring-nets.

In 1928, R. Rallier du Baby, while working off Newfoundland in a vessel fitted with an echo-sounder, noticed certain abnormal echoes which he attributed to the presence of shoals of cod. In the same year, a drifter from Boulogne found echoes which were associated with herring shoals and the first ultra-sonic sounder was installed in a fishing vessel in 1930.

The types used at the present time are: indicators, recorders and fischlupes, and the following makes are employed: Scam, Sadir Carpentier, Desmet, Atlas, Elac, B.B.T.(licence Kelvin), and Bendix.

Germany

Due to the war, echo-sounders were not installed in German fishing craft for fishing purposes until in the year 1949. Since that time the development has greatly improved and some vessels have several types of these sounders aboard. The echo-sounder is used for maintaining certain depths of the water with trawl-net fishing and equally for detecting fish shoals.

Fish detecting apparatus is mainly used in the white fish and herring fisheries, but also for fishing sprat, sardine, tuna, redfish, and mackerel.

All trawlers are equipped with echo-sounders. According to the information dated 1. January 1953, cutters of 18 m. in length, and occasionally even those of 14 m. in length, are equipped with echo-sounders for fishing purposes. 33 % of all deep-sea cutters are using echo-sounders, but only 13% of the drifter fleet are so equipped. Two of the four drifter companies own only one detecting device each. Thus the following survey can be given: trawlers 100%, deep-sea cutters 33%, and drifters 13%.

The situation with the cutters is very different, depending on their place of registration, either in the North Sea or in the Baltic. 43% of all deep-sea cutters of the Baltic fleet have echo-sounders for detecting the fish. Only 19% of the North Sea fleet, however, are equipped in the same way. This can be explained by the fact that, subsequently to the "Tuckzeesen" fishery, the Baltic vessels are undertaking an intensive pelagic trawl fishery with two vessels and are also participating in the oil-herring fishery.

Only the echo-sounders made by Atlas, Electro-Acustic, and Behm-Fahrenholz are being used. The particular models used are:

R, recording with graphite paper	75 %
CRT, fischlupe	22 %
CRTR, combined apparatus	3 %

The tendency is obviously to use a device for simultaneously observing the fish by means of the recorder and the cathode-ray tube. It would be desirable to improve the recording of fishes near the bottom in fresh-water fisheries.

Apparatus for horizontal sounding cannot be used in Western Germany for the time being, but there is a need for such instruments in fishing.

Holland

After some trials by a few progressive skippers in the years 1949—1951, many of the herring trawling fishing vessels (trawlers, luggers, and cutters) used the echograph for herring detection in 1952.

1953 was the first year in which the echograph was used for herring drift-net fishing by the luggers.

On 1. April 1954, the situation was as follows:—

Atlas fishfinder	1
Atlas echograph	19
Becker echograph	15
Behm echograph	2
Bendix echograph	4
Elac fischlupe and echograph	13
Elac echograph	10
Kelvin-Hughes MS 24	85
» » MS 22	15
» » MS 20	40
» » MS 12	4
	208

Of the 269 ships without recording echo-sounders, a total of 82 are equipped with a visual echo-sounder (mostly Raytheon).

Especially for the trawled-herring fisheries in the Channel the Decca navigation apparatus and the combination of the fischlupe and the echograph are much appreciated.

Ships fishing in pairs with the Larsen trawl in the Channel are all equipped with an echograph.

Asdic has not yet been tried in the Netherlands for fishing purposes.

Iceland

As far as is known, echo-sounding was first used in Iceland in 1930, the machine being made by Behm. Marconi instruments were introduced in 1934 and in 1938 the research vessel "þor" was equipped with a sounder with paper recorder.

For many years the sounders were used only for navigation but their use in searching for

fish has become more and more important. Herring and cod are the main species on which the sounders are used in connexion with purse-seines, drift-nets and otter-trawls.

About 90% of the decked vessels in Iceland are equipped with one or more sounders and these are distributed among the following makes:—

Make	Number of vessels	Year of introduction
Kelvin-Hughes	331	1949
Marconi	141	1934
Bendix	50	1951
Elac (fischlupe)	45	1950
Atlas	27	1951

In 1953 a patrol boat (52 m.) was equipped with an Asdic set (Kelvin-Hughes) for the purpose of locating herring shoals.

Norway

Echo-sounding is used extensively throughout the fisheries for herring and sprat, as well as for the capture of cod and mackerel.

Practically 100% of all fishing vessels over 100 ft. in length are equipped with sounders and it is estimated that there are some 4,000 instruments in use at the present time.

The types of echo-sounders in use are as follows: Kelvin-Hughes, Bendix, Simrad, Elac, Atlas, Fathometer, and ROB (French, made in Norway).

The Kelvin-Hughes sounders have for some time dominated the Norwegian market but recently, the Norwegian-made Simrad is gaining popularity. Following the success of trials with the Simrad horizontal type of shoal-finder, the claim for a combined Echo-sounder/Asdic is becoming more and more pronounced, especially for the great herring fleet.

Sweden

The echo-sounder for fish finding was introduced to Swedish fishing cutters during 1947, but already in 1943, two Swedish vessels had been equipped with sounders during their stay in Scotland.

With the development of the pelagic herring fisheries, the use of echo-sounders, and especially of recorders, increased considerably, and the gear used are mainly purse-seines, floating trawls and bottom trawls.

On the Swedish west coast, 600 echo-sounders are in use, and these are distributed among the manufacturers as follows: Atlas 50%, Kelvin-Hughes 33, Bendix 8, Elac 4, and others 5%.

In the Baltic, 150 sounders are in use, and they are distributed as follows: Kelvin-Hughes 33%, Atlas 33, Bendix 14, Elac 7, and others 13%.

The most usual type is the recorder, and only 10 cutters are fitted with cathode-ray tube sounders. Of these seven carry recorders in addition. The cathode-ray type seems to increase the possibilities of success so far as trawlers are concerned and it is felt that the high initial cost of these instruments is justified.

Asdic, Sonar or similar horizontal echo-sounders are not yet used by Swedish fishermen, partly because of the high price of such instruments, and also because of the small advantages offered by these devices in Swedish waters.

United Kingdom

The first echo-sounder to be used in a steam trawler was a sonic machine using an electric hammer as the transmitter and hydrophones as the receiver. This was installed by Messrs. Henry Hughes and Sons in 1928. In 1933, a sounder employing magnetostriction oscillators and paper recorder was used in the steam trawler "Glen Kidston", and between 1930 and 1935 the Marconi visual sounder became very popular with the fishing industry and it was with this instrument the echo-sounding research on the herring fisheries began in 1933.

At the present time, about 80% of the British fishing vessels are equipped with sounders, mainly in connexion with the herring, pilchard, and cod fisheries, and some small vessels using the Larsen trawl in the Thames Estuary also rely on sounders for locating sprat shoals.

Nearly all the sounders in use in the British fishing fleets are manufactured by either Kelvin-Hughes or Marconi, and these cover a wide range of models. The Kelvin-Hughes range consists of the fishing types MS 22 and MS 24 using moist paper, and the MS 26b using dry paper, and in addition there is the MS 24J/C.R.T. or "Kingfisher" incorporating a recorder with visual scale expander.

The Marconi range consists of the "Seavisa", "Seagraph", "Visagraph" (a combination of the first two), the "Graphette" using dry paper and the new "Seagraph, II".

Asdics are at present only used for whaling but horizontal echo-sounding for use in pelagic fisheries is being developed.

Table 1. Application and Distribution of Echo-Sounders in Various Countries.

	Belgium	Denmark	Finland	France	Germany	Holland	Iceland	Ireland
Species sought by Echo-sounder	Herring, Sprat, Cod	Herring, Sprat	Herring (Iceland)	Herring, Cod, Mackerel, Sardine	Herring, Sprat, Mackerel, Cod, Tunny, Redfish	Herring, Sprat, Mackerel, Cod, Whiting	Herring, Cod	Herring, Mackerel, Whiting
Gear used in Conjunction with Echo-sounder	Trawl, Pelagic Tr.	Herring Tr. Floating Tr.	Drift-nets, Purse-seines	Trawls, Drift-nets, Ring-nets	Trawls, Floating Tr. Herring Tr. Drift-nets, Trolling	Trawl, Herring Tr. Drift-nets	Purse-seines, Trawl, Drift-nets	Drift-nets, Seines
Year of Introduction	1945	1945	1949	1926—30	1949	1939	1934	1946
Smallest Vessel with Echo-sounder	24.6 tons (48 feet)	16 tons (36 feet)	325 tons	16 m. (52 feet)	14 m. (46 feet)	18.3 m. (60 feet)	12 m. (35 feet)	14 m. (45 feet)
Percentage of decked Vessels equipped	31 % (1951)	36 % of vessels over 15 tons (1953)	4 out of 6 Iceland vessels. None in Finland (1953)	—	Trawlers 100% Deep-sea Cutters 33% Drifters 13% (1954)	57 % (1951)	90 % (1954)	15 % (1951)
Types of Echo-sounders used	KH (R) 63 % M (R) 2 % Sc. (I) 35 %	A (R) 33 % KH (R) 27 % B (R) 25 % BF (R) 10 % Others 5 %	KH E A	(R) (I) (CRT) Sc. C DM A E BBT B	A (R) E (R) } 75 % BF (R) E(CRT) 22 % A(R+CRT) 3 %	(I) 52 % SSF E A M Sc. (R) 48 % KH B C	(R) KH 56 % M 24 % B 8 % A 5 % (CRTR) E 7 %	(R) 100 % makes not stated

(For explanation of symbols see p. 23)

Table 1 (continued).

	Norway	Portugal	Sweden	United Kingdom	Canada (Pacific)	Canada (Atlantic)	South Africa	United States
Species sought by Echo-sounder	Herring, Sprat, Mackerel, Cod	Cod, Herring, Sardine, Anchovy, Horse-Mackerel	Herring, Sprat, Mackerel	Herring, Sprat, Pilchard, Cod	Herring, Pilchard	Herring	For Navigation only	Sardine, Jack Mackerel, Pacific Mackerel, Anchovy, Herring, Salmon
Gear used in Conjunction with Echo-sounder	Purse-seines, Drift-nets, Trawl	Trawl, Purse-seines	Purse-seines, Floating Tr., Herring Tr.	Drift-nets, Ring-nets, Floating Tr. Herring Tr. Trawl	Purse-seines	Purse-seines (Bottom and Pelagic Trawls and Drift-nets used experimentally)	—	Purse-seines Lampara
Year of Introduction	1934	1936 - Trawls 1947 - Sardine	1947	1928	1945	1939 (Sonic)	1953	Nav. — 1936 Fishing — 1944—5
Smallest Vessel with Echo-sounder	5 m. (17 feet)	10.2 m. (34 feet)	9 m. (30 ft.) 25 ft. (Baltic)	11.5 m. (38 feet)	12 m. (33—36 ft.)	12—15 m. (40—50 ft.)	18 m. (ca. 60 ft.)	5 m. (17 feet)
Percentage of decked Vessels equipped	100% of Boats over 100 ft. (4,000 in all) (1954)	Navig. 87% Cod (Trawl) 100% » (Liners) 38% Sardine 68%	85 % (1954)	80 % (approx.) (1954)	Herring Boats 100% Trawlers 95%	100 % (approx.) of Atlantic Fleet	Trawlers and Whalers 100% Others*) under 1%	California 14% Tuna clippers (Nav.) 100% Purse-seiners 99%
Types of Echo-sounders used (For explanation of symbols see p. 23)	KH B S E A SSF ROB	(I) (R) (CRT) A E KH M B BF RA Sc. SSF	(R) 100% W.CoastA 50% KH 33% B 8% E 4% Others 5% Baltic KH 33% A 33% B 14% E 7% Others 13%	(R) 90% KH M (I) 10% M (CTR) KH	KH B EK	KH B SS BH EK	M(I) M(R)	(I) (R) Makes not stated

*) High price a deterrent.

Explanation of the Symbols shown in Table 1 and List of Manufacturers.

(I)	Visual (flashing light) sounder.
(R)	Sounder fitted with paper recorder.
(CRT)	Sounder with cathode-ray tube presentation.
(CRTR)	Combination sounder fitted with both paper recorder and cathode-ray tube presentation.
A	Atlas-Werke A/G, Bremen, Germany.
BBT	Barbier-Benard et Turenne, 82, Rue Curial, Paris, 19e.
BF	Behm-Fahrenholz, Kiel, Germany.
B	Bendix International, 72, Fifth Avenue, New York, 11.
	Bendix, 146, Champs Elysées, Paris.
	Submerged Log Co. Ltd., Parliament Mansions, Abbey Orchard Street, London, S.W.1.
BH	Bludworth Marine, Division of National-Simplex-Bludworth, Inc., 92, Gold Street, New York, 7.
DM (Desmet)	Société Générale d'Electricité et de Radio, 5, Rue des Margueritois, Faches-Thumesnil, France (Nord).
E (Elac)	Electroacustic, G.M.B.H., Westring 425-429, Kiel, Germany.
EK	Ekolite Ltd., 369, East Hastings Street, Vancouver, B.C., Canada.
KH	Kelvin-Hughes (Marine) Ltd., 99, Fenchurch Street, London, E.C.3.
M	Marconi International Marine Communication Co. Ltd., Marconi House, Strand, London, W.C. 2.
RA	Raytheon Manufacturing Co., Waltham, 54, Mass., U. S. A.
ROB	Robertson Radio-Elektro, Egersund, Norway. (Agents for Scam).
Sc. (Scam)	Société de Condensation et d'Applications Mécaniques 37, Rue du Rocher, Paris 8e.
C	Etablissements Sadir-Carpentier, 101, Boulevard Murat, Paris, 16e.
S (Simrad)	Simonsens Radio, Oslo, Norway.
SSF (Fathometer)	Submarine Signal Company, 160, Washington Street, Boston, Mass., U. S. A.
(AGA)	AB Gasaccumulator, Stockholm-Lidingö, Sweden.
(Radiola)	AB L. M. Ericsson, Stockholm 32, Sweden.

Suggestions to Manufacturers

AS a direct result of the experience of many workers in the field of echo-sounding as applied to commercial fisheries, several ideas connected with the various aspects of the science have emerged. These ideas are presented here, not as criticisms of any existing sounding instruments, but rather as suggestions towards the formulation of the *ideal echo-sounder*, if indeed such an instrument can possibly exist among the many different kinds of fisheries and fishermen.

One of the main features governing the choice of echo-sounders is the initial cost, especially to the skipper who owns his own boat, and some of the ideas listed below may not be entirely compatible with the policy of keeping manufacturing costs down to a minimum, nevertheless, they are presented so that designers may, if they so wish, compromise between one idea and another in a way that best suits them.

Frequency of Transmission.

The choice of transmission frequency for echo-sounders employed on fishing vessels will be governed by two important factors:—

(1) Increase in transmission frequency gives greater range of discrimination between sound scatterers.
(2) Attenuation of the sound beam becomes greater as the transmission frequency increases, thus reducing the range of the equipment.

It is undoubtedly true that the different requirements of the world's various fishing fleets can be met in a *single* machine only by incorporating a system giving a number of transmission frequencies, (say 15, 30 and 50 kc./s.), each of which may be selected at will by the operator on board ship.

Such a machine, while presenting no insuperable technical problems, would undoubtedly prove considerably more expensive than present-day single frequency machines and would demand greater accommodation space than could be provided on many of the smaller fishing vessels now using echo-sounders. It is probable therefore, that manufacturers will have to concentrate on standard single frequency machines for some time to come, but they should of course bear this need in mind.

It is considered that of the transmission frequencies in use in present-day echo-sounders, 30 kc./s. is the one which in general best meets the needs of the fishing fleets. The circumstances encountered in different fisheries, however, are so great that it is very desirable that a number of models of echo-sounders, employing different transmission frequencies, should be made available for fishermen. The following classification is suggested:—

(1) *Shallow-water fisheries*—up to 30 fathoms depth (50 m.) 50—80 kc./s.
(2) *Fisheries in moderate depths*—30—200 fathoms (50—350 m.) 30 kc./s.
(3) *Deep-water fisheries*—over 200 fathoms (over 350 m.) 10—30 kc./s.

Beam Angle.

The beam angle to be employed in "fishing" echo-sounders will again need to be chosen as a compromise between two factors.

(1) Reduction in beam angle increases the accuracy of shoal size determination.
(2) Increase in beam angle increases the area of search, and reduces the loss of echoes in rough weather.

It is more important for general fishing purposes that there should be the largest possible area of search, and since the adoption of a wide beam angle permits the use of smaller and cheaper oscillators, it is considered that beam angles of less than 15° are not necessary in fishing echo-sounders. The manual control of the beam angle would be considered ideal.

It is more important that the area of search should be as great as possible in a lateral direction and it is probable that an oscillator of rectangular design will prove the best type for general use.

Depth Scales.

As a result of the very variable requirements with regard to the depth scales to be used in echo-sounders, a large number of different models, each with its own characteristic depth scales and phases have been developed, and are now available. There are, however, two features which are considered desirable and which should be provided for wherever possible. These are:—

(1) The whole depth, from surface to sea-bed, should be covered by the recording.
(2) As much of the width of the recording paper as possible should be used at all depths.

These features can only be satisfied in general purpose echo-sounders by the incorporation in the machine of a number of selective basic depth scales, appropriate for the general range of depths over which the fishing vessels operate. Since most fisheries operate in depths less than 250 fathoms, it is considered that the basic scales should be selected to cover appropriate intervals within this depth range. The following four basic scales will probably satisfy most general fishing needs:—

0— 40 fathoms	(0— 75 m.)
0— 80 »	(0—150 m.)
0—150 »	(0—300 m.)
0—250 »	(0—500 m.)

but there will remain some fisheries which are carried on over much deeper waters, for which an even deeper scale is desirable.

The provision of suitable phases within each of the basic scales especially the deeper ones is also desirable in order that it may be possible to make a more detailed examination of a particular depth interval. 40 fathom phases, with a 10 fathom overlap, on the 0—150 and 0—250 basic scales are probably suitable for most general purpose echo-sounders.

The recent development of "combination" echo-sounders in which a paper recorder and C.R.T. presentation are worked simultaneously has increased greatly the selectivity of depth interval to be examined. This property undoubtedly increases the efficiency of the machine for the various types of fishery in which echo-sounders are now employed, and it is considered that "combination" sounders provide most of requirements of the general purpose echo-sounder, and consequently their use in fishing vessels will gradually increase.

Presentation.

(a) Amplification.

The tuning of the amplifier should be such that the minimum of extraneous frequencies, such as engine noise, etc., are recorded. Suppression is very desirable and easy means of adjusting it should be incorporated in the instruments for the use of skilled fishermen and scientific workers. The provision of a means for indicating on the recorder the amplification factor at each setting of the sensitivity control is considered desirable.

(b) The Recorder.

It is difficult to emphasize the use of dry or wet paper, for both have a place in echo-sounding. The dry paper gives a permanent record which is easily stored but it has usually a very short range of gradation which makes it difficult to distinguish between echoes of different strengths.

The wet paper, on the other hand, gives a long gradation of tones but, unless it is handled carefully and quickly, it is liable to fade rapidly. Further, in the case of certain makes of sounder, a large amount of wet paper is wasted because it dries on the machine when the latter is not actually in use.

There is much to be said for a sounder in which the paper moves horizontally rather than vertically, but with wet paper the horizontal type may be difficult owing to the top of the paper becoming too dry. In the case of dry paper used horizontally it would be advantageous if provision were made for winding the paper backwards so that a skipper could examine his earlier recordings on a given roll of paper.

So far as paper speed is concerned it would be desirable if this could be made variable so that the operator could select the speed which best suits the occasion. In any case, the speed should be kept low.

General.

There are several small points of a general nature which have a bearing on the popularity of any particular sounder, and one which, from the fishing skippers' point of view, is very important, is that the stylus should be visible

to the operator at the time the recording is made. This is particularly necessary when the skipper is searching for shoals which are not very dense, and it should not be necessary for him to have to open the instrument in order to watch the stylus.

The general preference for horizontal paper movement has already been mentioned, but no matter which style is employed it should be remembered that a skipper who is an echo-sounder enthusiast is constantly wanting to refer to recordings recently taken, and some kind of back-winding mechanism should be incorporated to allow him to do this.

The need for constant motor speed control cannot of course be too strongly stressed, for the accurate registration of the depth of fish shoals is very important to herring fishermen.

It is also extremely convenient to have some provision made for coupling the electric log to the echo-sounder, so that the extent of a fish shoal can be easily gauged. This will naturally apply to larger fishing vessels.

Finally, while it is not considered absolutely necessary that sounders should be self-contained in one single unit, it is important that all instruments should be as small as possible without sacrificing efficiency so that skippers can have the machine installed in the place he considers most suitable, and, in order to deal with temporary break-downs at sea, it could be very convenient if there was some standardization of components within each make of sounder so that units could be exchanged by non-technical operators.

CONCLUSION

A general outline of present-day echo-sounding as applied to commercial fisheries has been given in the foregoing pages, and, as far as the future is concerned, it is felt that the main requirement will be need for extending the area of search. This will undoubtedly lead to an increased use of oscillators which can scan in a more or less horizontal direction.

A further development will probably be the increased use of sounders which combine basic-scale paper recording with selective phasing with C.R.T. presentation. Such systems are likely to become a requirement of bottom trawling.

Finally, no matter what the future trend of echo-sounding, the need for rapid and expert servicing of instruments in all fishing localities cannot be too heavily stressed, for, apart from the considerations of initial cost and renting facilities, nothing contributes more to the popularity of a sounder than good service.

Appendix I

A Proposal for the Introduction of Organized Echo-Search in North Sea Herring Investigations

By
B. B. Parrish.
The Marine Laboratory, Aberdeen.

Apart from its direct value to the pelagic fisherman, the recording echo-sounder is an important tool in a number of fishery biological studies. Of these, perhaps the most important are studies of stock distribution and migration. The application of this gear, and the closely allied equipment Asdic, to this type of investigation is well illustrated by the recent work by Norwegian scientists in the Norwegian Sea (Devold, 1952).

Before the echo-sounder can be used effectively in this sort of investigation it is necessary that the types of traces given by any species of fish should be reasonably accurately known. Not until this difficulty has been overcome can the results of echo-sounder surveys be interpreted with confidence for any one species. In some areas, where only one pelagic species is found in abundance at any one time, this problem may be relatively easily solved; but, in those areas which maintain concurrently two or more pelagic species, it may necessitate very careful study of echo-charts taken over large areas and long time periods, with extensive sampling of the species giving rise to the traces. Even after intensive study it may be found that identification of any one species from the echo-charts alone cannot always be made with complete confidence because of the similarities between the traces resulting from shoals of different species. In fact, the usefulness of the echo-sounder in such studies as those mentioned above hinges very largely on the degree of confidence with which traces given by the species under investigation may be identified on the echo-chart.

The Identification of Herring Shoals in the North Sea.

The identification of herring on echo-charts recorded in the North Sea has received much attention, notably by English, German and Scottish workers, following the large-scale introduction of the equipment in the herring fleets since 1945. The main principles underlying this work are discussed by Craig in his paper published in this volume (App. II). The problem has been facilitated in two important respects: (1) much was already known about the shoaling habits and behaviour of herring in the area, and (2) they are usually the only pelagic species present in abundance over a large part of the North Sea. This is particularly so in the northern regions, clear of the coasts.

The important result which emerges from these investigations is the association of a class of traces, sometimes called "plumes", with herring. Scottish investigations have shown that "plume" traces are associated with herring over the northern North Sea fishing grounds, particularly during daylight, in spring and summer, and German records illustrate the same type of trace from the Fladen, Gut and Dogger Bank areas. English results (Cushing, 1953) show that this type of trace is common also in the southern North Sea.

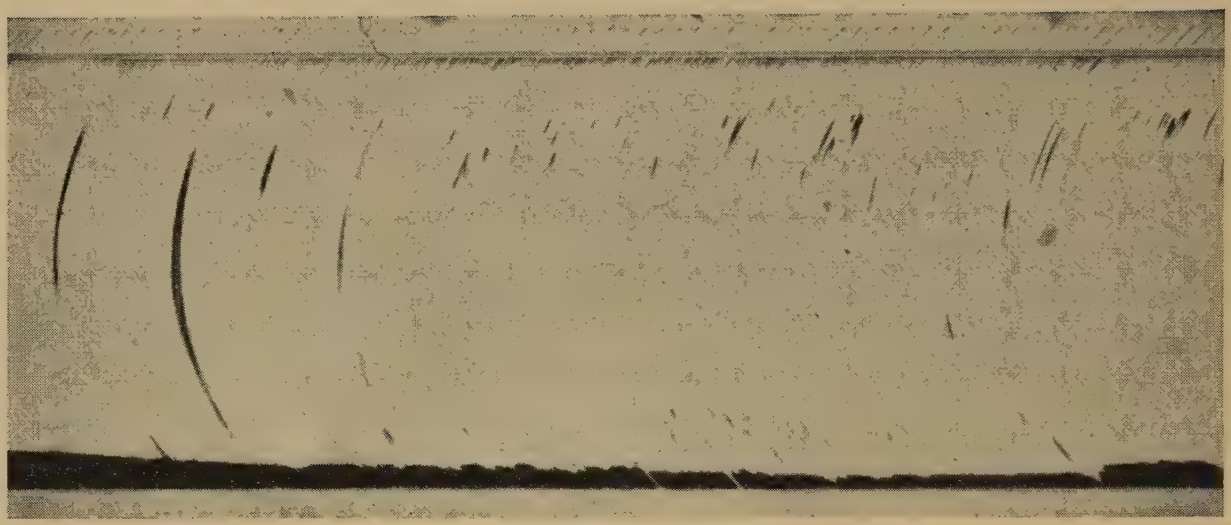


Figure 1.
Large and small "plumes" recorded throughout water column.
Approximate position 59°N., 2°30'E. Date: 5. May 1953
Time: 1700—1730 hrs. Speed of ship = 8 knots
Echo-sounder: Kelvin-Hughes MS 24 Paper speed = 0.5 inch/minute
Distance covered by echo-chart = 4 miles.

Figure 2.
Group of prominent "plumes" off sea-bed.
Position 58°18'N., 01°15'E.
Date: 5. May 1953
Time: 0530 hrs.
Speed of ship = 7 knots
Echo-sounder: Kelvin-Hughes MS 24
Paper speed = 0.5 inch/minute
Distance covered by echo-chart = 1 mile approx.

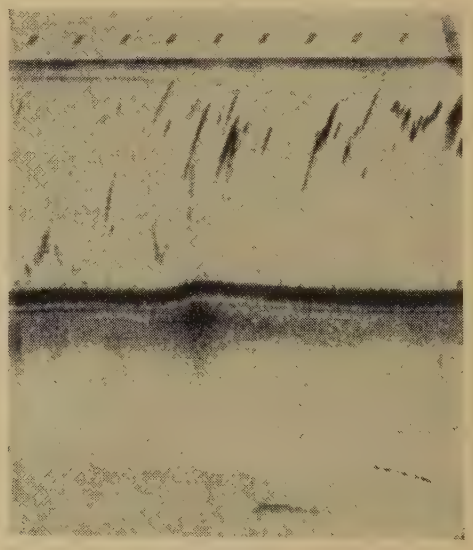


Figure 3.
Irregular "plumes" in mid-water.
Position 59°31'N., 02°15'W.
Date: 14. June 1953 — Time: 2230 hrs.
Speed of ship = 14 knots approx.
Echo-sounder: Kelvin-Hughes MS 21 b.
Paper speed = 0.5 inch/minute.
Distance covered by echo-chart = $^1/_2$ mile approx.

Some examples of this class of traces, illustrating the sort of range of variation which may be encountered, are presented in Figures 1 to 3[1]).

While it cannot be claimed that herring can always be identified on the echo-chart, it is evident that at least in the areas north of the 100 metre contour during spring and summer, particularly in daylight, the "plume" trace can be labelled herring with reasonable confidence. Furthermore, it is considered that sufficient is known of the appearance of traces, other than the "plume", to which herring give rise in different areas and seasons for confident assessments of herring distribution to be made by experienced workers from large-scale echo-sounder surveys over the North Sea.

A proposed Programme of Echo-Search for the North Sea.

One of the important preliminary results which has emerged from the recent international programme of herring tagging in the North Sea and neighbouring areas has been the wide scatter of tagged fish from the points of liberation. From these results alone there is evidence of considerable interchange of stocks between the various fishing grounds, some of which are widely separated. While important advances towards a fuller understanding of stock interchange and migration of the North Sea herring are being, and will continue to be, made from tag recoveries, it is unlikely that the full story of herring movement will be completed without the introduction of other methods of investigation.

Two additional methods of approach are possible; firstly, extensive sampling and analysis of the fish stocks in all areas where herring are found in abundance, and secondly, the introduction of frequent extensive echo-sounder surveys over the North Sea. The first approach is being pursued by most European countries at the present time and the results from some sources are being published in *Annales Biologiques*. But no attempt has yet been made to introduce a coordinated programme of echo-search, from the results of which the movements of the main centres of herring in the North Sea might be followed and plotted throughout the year. Hitherto, only localized surveys, covering specific fishing grounds and seasons, have been made (Cushing, 1952, 1953; Craig & Parrish, 1952).

The Employment of Search Vessels.

Two important factors which govern the success of a programme of this sort are the intensity of echo-search and the frequency of survey; the greater the intensity of search the more accurately can the centres of population be plotted, and the more frequently the surveys are made the more detailed can be the assessment of the migration patterns. The intensity and frequency adopted in practice must be conditioned on the one hand by the available facilities and costs of operation, and on the other by the direct benefits which the surveys would bring to fishermen operating in different areas at the time, and by the minimum data necessary for significant biological analysis.

It cannot be denied I think that, considerations of cost apart, the best method by which an intensive echo-search programme could be conducted would be by search vessels equipped with the best echo-sounders available, and employed specifically for this purpose for the duration of each survey. While it is probable that the detailed requirements might differ to some extent between areas and seasons, it is considered that for the fullest biological benefit the surveys made by the search vessels should be conducted on a regular and close grid, to be completed within the shortest practicable period (say, one week), some 10—15 times each year. A possible survey grid is shown in Figure 4.

An essential requirement for the successful working of any such programme is a centre for integrating all information collected by the search vessels. This might consist of a team of workers, experienced in echo-chart interpretation, to whom all echo-charts taken during the surveys would be forwarded for analysis. Alternatively, and perhaps preferably, the records taken in different parts of the North Sea could be analysed by local workers having expert knowledge of echo interpretation in their respective areas. Their results would be sent subsequently to a central pool where composite plots covering the whole North Sea could be made and issued to all interested workers. During the course of each survey, of course,

[1]) The actual form of the trace will of course depend on the composition and size of the fish shoal, and also on such factors as the distance of the fish from the oscillators, the speed of the recording vessel relative to the shoals, and the beam angle and paper speed of the echo-sounder.

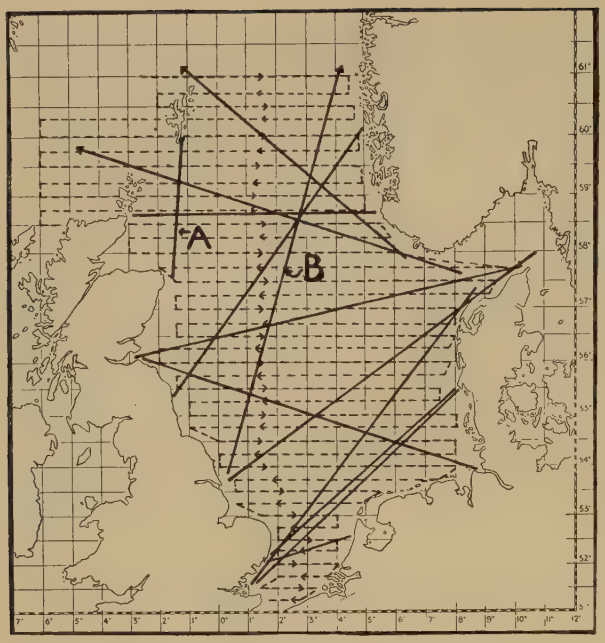


Figure 4.

Chart showing proposed echo-search coverage of the North Sea.

--➤-- Proposed North Sea echo-sounder survey grid.

—➤— Approximate routes followed by some shipping lines and commercial trawl.

A = Route worked by S/S "St. Clair".

B = Approximate route of British Arctic trawlers working from Humber ports.

each search vessel could impart up-to-date information on the whereabouts of fish concentrations to fishermen working in the area, either of their own or all countries.

Unfortunately, the practicability of such an undertaking is difficult to gauge at the present time. It must be admitted that the proposals made above are expensive, and that a programme of this magnitude could only receive serious consideration if satisfactory evidence of its worth had been obtained. However, it may now be claimed that in several areas the immediate financial benefits to the fishermen alone would more than pay for the cost of operation so that the overall cost of the entire operation would be much less than might be expected. (Indeed, it seems likely that search vessels may soon be introduced in some areas at the instigation of commercial interests on the expectation of substantial financial reward). Therefore, it is urged that the scheme should not be discarded too lightly, because of the real direct benefit which it could well bring to the commercial fisheries. In the first place, it might be practicable to undertake an initial costing trial, involving one or two search vessels, over only part of the North Sea, in conjunction with the supplementary surveys mentioned below.

Other Sources of Information.

Even if such a programme of organized echo-search proves impracticable in its entirety at present, many valuable data on herring distribution and movement can still be accumulated from other as yet largely untapped sources. Of these, the most important are: (1) research vessels, and (2) regular freight and passenger ships, and commercial fishing vessels (especially those on regular passage over the North Sea to and from distant fishing grounds), as was envisaged for the more northern waters in the resolution passed by the Consultative Committee in 1949 (Rapp. et Proc.-Verb., **127**, p. 36).

Research Vessels.

While those research vessels employed directly on herring investigations in the North Sea are often engaged in programmes of intensive echo-search from which biological data are being collected, it is probable that at present insufficient use is being made of those not engaged in herring research as sources of echo-search data. It is considered that valuable information would accumulate if echo-search was carried out by all research vessels during their North Sea operations and if these data were forwarded to a central pool for analysis.

Although this source of data would undoubtedly prove of great value in the investigation envisaged, it is unlikely that it would alone provide the required intensity and frequency of echo-search. It is probable, therefore, that unless special search vessels were provided, additional sources of data, to supplement those derived from research vessels would be necessary.

Commercial Shipping Lines and Fishing Vessels.

Other sources of data which we have begun to use in the northern North Sea recently comprise the regular commercial shipping lines operating in the North Sea and long distance British trawlers on passage to and from northern waters. Their chief merits, particularly of the first, are their constancy of route and the relatively small cost at which their frequent records can be made.

The first shipping line utilized in the Scottish area was that operated between Aberdeen and

the Shetlands by S/S "St. Clair" owned by the North of Scotland and Orkney and Shetland Steam Navigation Company. The route surveyed, which is completed twice in each direction each week, is also shown in Figure 4. The strategic value of this particular route is that it traverses the areas fished by the drifter fleets operating from the Scottish east coast and Shetland fishing ports so that regular information on the whereabouts of herring concentrations can be given to the commercial vessels. This route is also of particular biological interest in that it crosses the Orkney-Shetland Channel, through which Atlantic water may enter the North Sea.

Once the cost of the echo-sounder and its installation had been met initially, the running costs of this scheme are restricted to the purchase of recording paper, repairs and maintenance of the equipment. Almost immediately, the direct benefit to fishermen from information obtained along this route far more than balanced the initial costs and running for the first year, and, meanwhile valuable biological information is being accumulated at relatively negligible cost, with further fishing benefits.

It should be noted that the echo-sounder installed on S/S "St. Clair" is of standard commercial pattern, with a pierced-hull installation. Records of the highest quality have been taken at the vessel's running speed of approximately 13 knots.

There is no doubt that data of both immediate and long-term value could be accumulated at relatively small cost if similar echo-sounder surveys could be conducted over the main shipping routes in the North Sea, not only those crossing important herring fishing grounds but also those over the "blank" areas. Some routes, over which regular European shipping lines operate, which it is considered would provide further valuable regular data, are also shown in Figure 4.

Although less frequent and regular than those taken by "St. Clair", data collected recently from long distance trawlers running between the Humber ports and the Arctic fishing grounds have demonstrated the value of this source of information. Again, a number of such records have been collected at relatively negligible cost.

Recommendations.

It is considered that the pooling of regular echo-search data taken over the North Sea and neighbouring areas would provide valuable information on outstanding problems of herring biology. While it is hoped that a programme of organized echo-search, involving special search vessels, may soon prove practicable, it is meanwhile recommended that immediate steps be taken to pool data from as many other sources as possible. Those which are considered most practicable and least costly are research vessels, commercial shipping lines, and fishing vessels. The quality of the data obtained from the one shipping line utilized regularly in the North Sea so far, prompt the strong recommendation that this source be utilized to the fullest extent possible.

Appendix II

The Use of Echo-Sounder in Fish-Location — A Survey of Present Knowledge, with Notes on the Use of Asdic

By
R. E. Craig,
The Marine Laboratory, Aberdeen.

INTRODUCTORY

SINCE 1933, when the first tentative experiments were made by Skipper Ronald Balls (1948) of Lowestoft and by Oscar Sund (1935) progress has been made in this subject, and its importance has attracted the attention, since the recent war, of many workers in different countries. A number of papers have been published, each adding some piece to the assemblage of facts, and this paper attempts to state what is known as briefly as possible.

The writer has, in fact, set out to answer some af the numerous questions that have been asked by biologists concerned in echo-surveys for fish, and have included only such preliminary matter as seemed necessary for this purpose.

Types of Echo-Sounder.

At the end of the war, the recording echometer was the only standard equipment efficient for the detection of fish. This equipment converts the received echo signal into a brief electrical pulse which is applied to the recording paper (starch iodide, or coated graphite paper), making a mark whose position depends on the time elapsed since transmission and so on the depth of the reflecting object. Recently a German equipment has been introduced, the Elac "fischlupe" (Electroacustic, 1950 a, 1950 b) which presents the returned echo, unrectified, on a vertical time base on a cathode-ray tube. Reports on this equipment suggest it to be a valuable adjunct to recording echometers, but do not suggest that it alone is likely to supplant these as standard fittings to fishing vessels.

In all these equipments, magnetostriction oscillators working at 10—30 kc./s. have apparently proved to be the most popular, though it will be appreciated that except in the case of the "fischlupe" most standard machines have been designed principally as navigational instruments, and the fish-finding possibilities have been until very recently of secondary importance. Some firms have adopted piezo-electric oscillators on frequencies up to 60 kc./s. No comparisons of these with the lower frequency machines have been published within the knowledge of the writer.

Fish Finding.

Echoes due to fish, other marine creatures, or objects above the sea bed, are identified as such if the echoes from them appear either (a) distinct and above the sea bottom, or (b) contiguous with the sea bottom but distinguishable from it.

This simple rule, however, can only be applied with the qualification that most echo-sounders produce certain spurious markings due to (a) interference between the transmitting and receiving oscillators, (b) deficiencies of the receiver amplifier, (c) engine noise, picked up by the receiving oscillator, which sometimes varies in character according to the depth

of water, (d) interference from other electrical gear on board and (e) echoes from bubbles under the ship, which may become a serious hindrance in bad weather. The observer should, therefore, be familiar with the peculiarities and deficiencies of his own machine, for only then can he assert with confidence that any particular trace is due to some object or objects in the sea.

Experience with echo-sounders leads to the recognition that marine organisms produce recordings of a number of different types which can be classified and recognized again and again, though unfortunately the classes of echo-traces merge one into another, making definition difficult and leading to the concept of echoes of a number of "typical" forms which have to be illustrated rather than described.

The Approach.

An advance on two fronts is necessary and has in fact been made.

(a) The first method of attack is by attempting to catch and identify the organisms responsible for a particular type of echo-trace. This is not easy, owing to the difficulty of fishing at precise depths, or in small well-defined areas, and to the difficulty of catching all possible scattering organisms with any one net. Two examples may illustrate this. The deep scattering layer is thought to consist of a mass of small organisms (Dietz, 1948; Moore, 1950) probably providing food for larger predators. It is difficult to know whether the resulting echo-trace should be assigned to the small organisms or to the larger predators, or perhaps to both. The second example is also of practical interest. Over many European waters, the thermocline or discontinuity layer is a marked feature of the summer months, and it is now known that frequently there are large concentrations of various organisms just at this level of discontinuity. This led the earlier investigators to believe that they were obtaining echoes from the thermocline itself, owing to the "abrupt" change in the transmission characteristics of the water.

Now the calculation of the intensity of possible echoes from the discontinuity layer is rather a delicate problem in mathematical physics to which the writer has not seen a satisfactory answer, but with increasing experience of echo-sounder work over the whole North Sea, it is now generally accepted that no detectable echoes can be attributed to water discontinuities themselves, and that the earlier assertions were based largely on the need to account somehow for echoes from a particular depth, which turned out to correspond well with that of the thermocline. This view has been supported by others (Trout *et al.*, 1952).

A more fruitful variation of the first method of attack has been that exemplified by the very first work in this field, that of Skipper Balls. This is the application of knowledge of fisheries and general biology of the sea to assess possible interpretations. There is after all a body of information on such matters as diurnal migration, occurrence of certain species in a given area at certain times of the year and so on. This information has been accumulated in the course of perhaps a century of observation and fishing. If a similar body of data could be accumulated for echo-traces, the interpretation of many of these would become obvious. Results are sought more quickly by planned experiments—in the case mentioned above Skipper Balls fished consistently in areas characterized by echoes obtained on his early type of echo-sounder. He was able to show that on the average he had bigger catches of herring than other ships and thus that most distinct echoes on the herring grounds were associated with these fish.

With the resources of modern fishery research, it is possible to collate the results of echo-surveys with the catches of a whole fleet (Krefft & Schüler, 1951; Cushing, 1951) and thus to get similar results more quickly, and another example of such a correlation was described by Mr. Parrish at the Amsterdam meeting in 1951 and has since been published (Parrish, 1952).

(b) The second method of attack is, through electrical engineering and planned physical experiments, to try to determine what type of echo is to be expected from a given arrangement and type of object under the surface. This approach, if carried out in a controlled manner, should serve three important purposes: (1) suggest solutions missed in the first method, (2) allow us to rule out some possibilities suggested by the first method and (3) point the way to the development of better fish-finding equipment in the future.

THE DEDUCTIVE METHOD

I. Single Scattering Point.

The supersonic pulse from the transmitting oscillator is in the form of a train of waves whose envelope takes the form of a relatively steep rise (GABLER, 1950) to a brief maximum followed by an exponential decline to zero (Figure 1). If the receiving amplifier is able to amplify and rectify this without distortion, which we shall assume to be the case, the d.c. pulse finally applied to the recording paper as the result of an echo from a single scattering point will have one of the forms shown in Figure 2.[1])

A certain minimum voltage A_0 is required to give a mark on the recording paper. It will be seen that as the peak amplitude of the incoming signal increases from A_1 to A_4, the length of the stroke made by the stylus increases from L_1 to L_4, i.e., for any given paper sensitivity the length of the stylus stroke will increase with increase either in the strength of the echo, or in the sensitivity of the amplifier. The depth of colour of the mark on the paper will be a function of the excess of voltage above the critical value A_0, but this function has not yet been stated, and it will clearly depend, as will A_0, on the quality and moisture content of the paper.

A single echo will, therefore, give rise to a stylus mark rising sharply to a maximum intensity, and then fading in intensity, and its length will be, for a given transmitter pulse shape, dependent on its strength and the amount of gain (i.e., amplification) used, and the proportion of faint tail to bold stroke will also depend on these factors. A single target stationary beneath the keel of a ship will give rise to a succession of such strokes.

FIG.1.

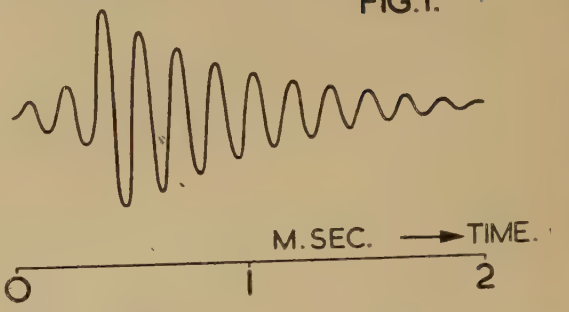


FIG.2.

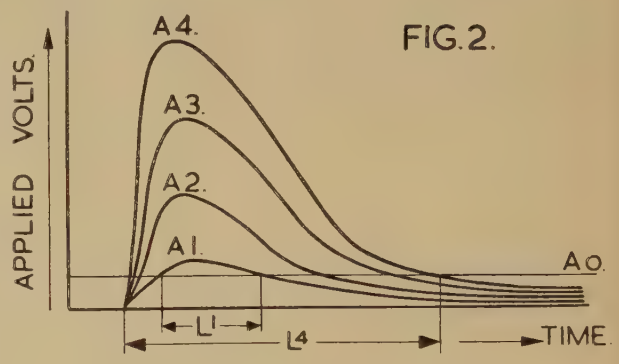
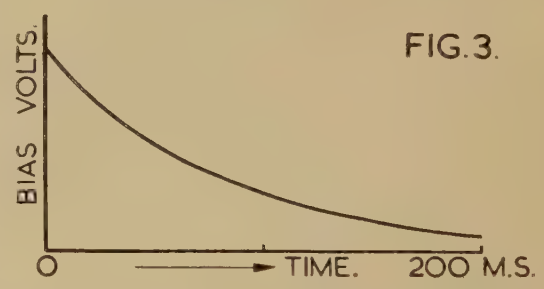


FIG.3.



Dependence of Echo Amplitude on Depth.

The amplitude of the echo from a target of given small size varies inversely with the square of the depth below the oscillators, except at distances from the keel as small as, say, five times the distance between the oscillators. At such small depths the assumption that the target can be vertically below *both* oscillators is not tenable and so the echo amplitude falls below that to be expected from the inverse square law. At depths below 200 m., absorption of energy by sea water becomes appreciable but we shall ignore this effect in subsequent treatment. (The factor involved at 15 kc./s. is of the order of $e^{-\cdot 000075d}$ where d is the depth in metres).

All commercial echo-sounders have provision (SPARLING, 1945) for what is known as "initial suppression", i.e., means for reducing the degree of amplification for a short period after the transmission, corresponding usually to sounding depths of the order of 120 m. This provision avoids the blacking-out of the paper by echoes from scatterers close under the ship, and provides a kind of automatic gain control for the echo-sounder to save continual adjustment of the manual gain control. This initial suppression is achieved by applying a negative bias voltage to one or

[1]) In the Bendix machine, which incidentally uses the relatively high frequency of 50 kc./s. with graphite paper, the signal is not rectified, and so a voltage of the form of Figure 1 is applied to the paper.

more of the amplifying valves just before the transmission occurs. This bias voltage drains off the valves at a rate determined by a resistance-capacity circuit, and the draining off is, therefore, exponential (Figure 3).

The variation in gain of the amplifier under this changing bias depends on the characteristics of the valves used, and on any standing bias on them. The manufacturer normally provides controls for the adjustment both of the initial bias and of the time constant of the resistance-capacity circuit which discharges the bias.

How gain should depend on depth is not a straightforward question. If our purpose is to maintain constant density of trace from a given small target at all depths then, from what has gone before, we clearly require that the gain should increase in proportion to the square of the depth. If this were done, however, we should get considerable blacking-out at depth, since in practical conditions the number of scatterers may be expected to increase with the increasing cross section area of the effective beam. Also echoes from the sea-bed have an amplitude which is inversely proportional to the depth ($1/d$ in contrast to $1/d^2$ for a target of fixed size) and so the bottom echo itself would increase in amplitude in proportion to the depth. As most echo-sounders have been designed primarily for navigation, they have been designed to keep the *bottom* echo amplitude as constant as possible and so the gain is designed to increase roughly in simple proportion to the depth. Our target of fixed size will, therefore, give rise to a pulse applied to the recording paper whose amplitude is (roughly) inversely proportional to the depth.

Beyond the limits of initial suppression, if the gain of the amplifier is kept constant, the bottom echoes decrease as $1/d$ but a fixed target echo decreasing as $1/d^2$ will rapidly disappear. For deep water sounding it is normally possible to increase the overall gain by means of the manual gain control, ignoring the blacking-out that results in the recording of the upper water layers. A limit to the overall gain is set by random interference such as engine noise, wave noise, and the inherent faults of valve circuits. It is possible that on many ship installations which are subject to vibration, microphonic noise generated in the valves also plays a part in producing spurious marks. If sensitivity of the echo-sounder is to be increased beyond the limits set by this random interference, it is necessary to increase the power of the *transmission*.

It should be emphasized that as a result of initial suppression there is no simple dependence between amplitude of the received echo as applied to the paper, and depth of target. If quantitative experiments are to be carried out it is necessary to calibrate the echo-sounder with a standard target, placed at known depths. The difficulty of getting a standard target vertically beneath the oscillators at any great depth will be obvious.

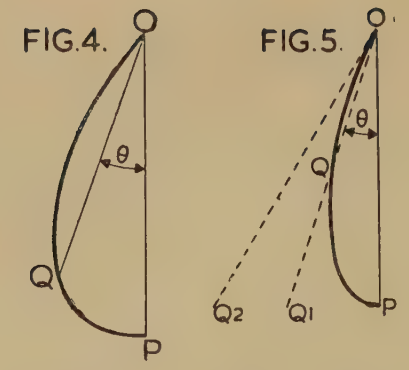
An improvement in the normal method of initial suppression has been suggested (Gabler, 1950), using two resistance-capacity circuits of different time-constant applied to two successive amplifier valves. This gives the possibility of much more precise control of the variation of gain with depth.

Dependence of Echo Amplitude on Angle.

The Polar Diagram of a *transmitter* defines the angular characteristics of the beam. If at a given depth the pulse amplitude at a target vertically below the ship is represented by the distance OP then the diagram indicates that at a target at the same *distance* from the oscillator but at an angle θ, the pulse amplitude will be given by the length OQ (Figure 4).

The Polar Diagram is usually assumed to have circular symmetry, i.e., it makes no difference whether the angle θ is taken fore and aft or athwartships. While the oscillators themselves have circular symmetry, this assumption may well be upset by the presence of the ship's hull, and depends on the mode of installation. If the Polar Diagram is required, it should be determined experimentally for each installation, and where this is not done, a formula borrowed from optics is generally applied which gives a half-beam width of arc $\sin 1.22\ \lambda/d$ where λ is the wavelength in water, and d is the diameter of the oscillator or tank (Gabler, 1950). This is true on the assumption that the whole face of the oscillator moves undistorted, which is not very probable. However the formula shows that beam width decreases with increase in the ratio d/λ.

The receiving oscillator also has directional properties in that it will respond more freely to an echo coming from directly beneath it than it will to an echo falling obliquely upon it. Its directional properties can also be re-



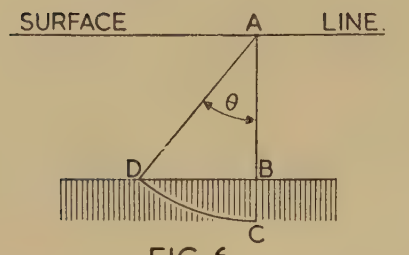


FIG. 6.

presented by a Polar Diagram which is usually of identical form to that of the transmitter, since identical oscillators are commonly used for both purposes.

Combining these two effects we can deduce an overall Polar Diagram. To put the matter more simply, we have for the amplitude of the transmission at the target, $A = \text{Const.} \times f(\theta)$. And for the sensitivity of the receiver, $S = \text{Const.} \times f(\theta)$ where we are assuming identical Polar Diagrams for transmitter and receiver. And so for the amplitude of the final echo we have $E = \text{Const.} \times [f(\theta)]^2$. Plotting this for a typical case we have the Polar Diagram shown in Figure 5.

It will be remembered that this diagram gives the variation of received echo amplitude with the angle θ from the vertical made by the line to a target, at a fixed distance from the oscillators. It is supposed to apply to a spherical target or a small flat plate kept always perpendicular to the line through the oscillators. It would not apply for instance to a flat plate kept horizontal, for this would be a less effective reflector to a pulse striking it obliquely than it would be to one meeting it normally. The target is assumed to be at the same angle with respect to both oscillators and so, for an object close under the keel, the athwartships Polar Diagram will be somewhat modified.

As a simplification it has become usual to speak of the effective beam as consisting of a central core of angle POQ_1, where $OQ = \frac{1}{2} OP$, and a "fringe" Q_1OQ_2 within which a target may still give an appreciable echo. No hard definition of this zone is usual, and it will be clear from these remarks that effective beam angle is a very crude expression and the angular zone from which echoes may be received is dependent on the depth and size of the target and the gain of the amplifier.

It may be pointed out that examination of the bottom echo gives some indication of beam angle. Suppose we are over a flat sea bottom, and our echo has the appearance shown in Figure 6. The depth of water is given by AB and echoes are being received from distances up to AC. These echoes must therefore come from points on the bottom on the circle on centre B and radius BD, so that θ, as shown is the effective beam angle. Now the chance that a pulse reaching D will be reflected back towards A is clearly much greater if the bottom be rough stone or rock than if it be smooth sand or mud. Hence in a given depth of water the effective beam width for bottom echoes is greater on a rough bottom than on a smooth one, hence the thickness BC of the bottom recording is also much greater. This provides a useful guide when trawling on the edge of rough grounds, for the thickening of the bottom echo appears just before the ship reaches the rough ground, and is noticeable long before irregularities of the bottom depth become so (see Figure 7).

It should be emphasized that the "effective beam angle" obtained by this method on rough ground is much larger than the angle within which we would expect to detect fish other than in heavy concentrations.

We are now in a position to study how the amplitude of the echo from a single target depends on the position of that target beneath the ship. We examine first the zone of depth within which initial suppression is applied and we have shown that within this zone the echo from the target has an amplitude proportional to $1/s$ approximately where s is the distance of the target from the oscillator. (It will be recalled that this is true because the gain of the amplifier *increases* in proportion to s). We assume the target to be a sphere. Now on our overall Polar Diagram (Figure 5) the echo amplitude from a target in the direction θ is proportional to OQ. Let us now regard P as the position of a target under the oscillators O; the distance OP now represents s. Let the

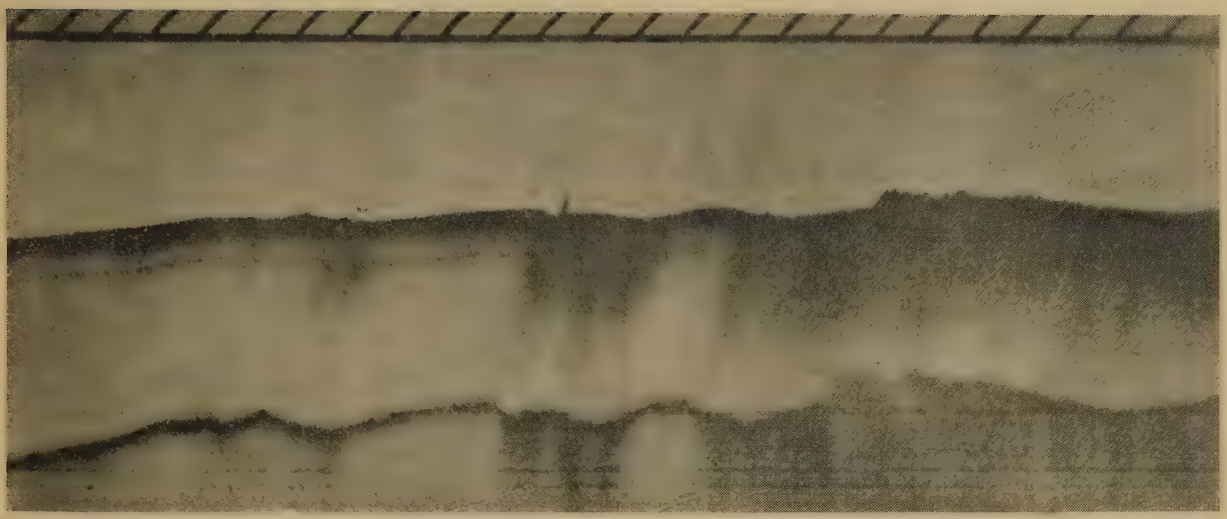


Figure 7. Effect of hard ground on echoes.

echo amplitude from the target at P be E_p. Then the echo amplitude from the target if moved to Q_1 (s unchanged), will be $E_{q1} = EP. \frac{OQ}{OP}$. The echo amplitude due to the target if placed at Q will be $E_q = E_{q1} \cdot \frac{OQ1}{OQ} = E_{q1} \cdot \frac{OP}{OQ}$ since $OQ_1 = OP$ and this gives us $E_q = E_{q1} \cdot \frac{OP}{OQ}$ $= E_p \cdot \frac{OQ}{OP} \cdot \frac{OP}{OQ} = E_p$, i.e. with a given target *all points on the curve OQP give rise to echoes of equal amplitude.* This allows us to draw out the "field" of the echometer since the lines of equal echo amplitude will be a set of curves similar to the Polar Diagram, but on different scales (Figure 8). Beyond the zone of initial suppression, of course, echo amplitude from the target begins to fall off inversely as the *square* of the distance, consequently the lines of equal echo amplitude extend much less deeply. This case can be easily worked out and plotted when it is necessary to deal with echoes from deep water. From a determination of Figure 8 by quantitative experiments for the particular echo-sounder in use, it is possible to make certain predictions about the echoes to be expected from a moving target, or one over which the ship is steaming.

To amplify the preceding section we shall recapitulate the procedure envisaged.

(a) Determine by tank experiments the Polar Diagram of one oscillator, $f(\theta)$.

(b) Draw up the function $[f(\theta)]^2$ giving the combined Polar Diagram.

(c) Draw up the field of the echo-sounder as in Figure 8 in which each curve is geometrically similar to the combined Polar Diagram, and the echo amplitudes along the line vertically through the oscillator are calculated from the $1/d$ rule. The field gives us the relative echo amplitude for a given target placed in any position. (Clearly if we choose some definition of scattering cross section, such as RAITT's [1]), we can if we please plot out absolute echo amplitudes).

Echo amplitude from the given standard target at a point, is a measure of the efficiency of detection at that point and, below some particular value, the standard target will no longer be detectable. If we suppose this minimum value for detection of the standard target is the value represented by 3 in Figure 8, then the outer curve in that figure defines the zone within which the standard target is detectable. We say the standard target is detectable at echo level 3.

(d) To any other target we require to allot its echo level for detection, and when this is

[1]) **RAITT's definition of scattering cross section.**
Let e_1 be the voltage amplitude of the transmitted pulse received at the receiver terminals when the receiver is faced towards the projector at a distance of 1 metre. Let e be the voltage amplitude at the receiver terminals produced by the echo from a target. Then if this target be placed on the sound beam axis at a distance of R metres, its scattering cross section σ, in square metres, is defined by the equation $(e/e_1)^2 = \sigma/4\pi R^4$.

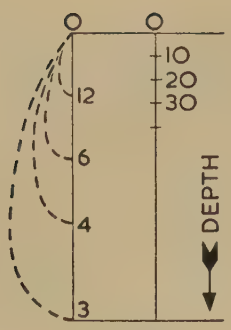


FIG. 8.

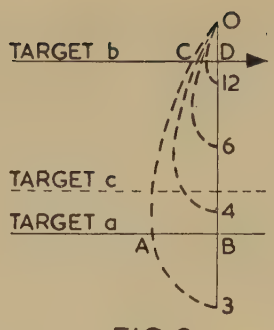


FIG. 9.

done, we have from our diagram the zone within which this target is detectable.

In Figure 9 I have plotted the course of two identical targets (a) and (b) moving under a ship. We suppose the echo level 3 is the lower limit of detection for these particular targets, and observe that the target (a) will be detectable from the point *A* till it comes under the ship at *B* and thence for an equal distance beyond *B*. It will first be detected at a distance *OA* from the oscillators and this will be recorded on the echo-sounder as a *depth*.

The resultant echo patterns on a recording echo-sounder are therefore as shown in Figure 10 (v. Brandt & Schärfe, 1950; Schüler & Krefft, 1951). We have already shown that the strokes resulting from strong echoes will be longer than those from weak echoes, and this has been indicated in the diagrams. The difference is much more marked in the case of target (b) than in the case of (a) for the former passes through a much greater range of echo strength during its period of detectability than does the latter.

The actual proportions of the resulting trace depend clearly upon the relative speed of target and ship, on the speed of movement of the recording paper, and on the depth scale in use, as well as on the reflecting power of the target. For instance, we suppose a target (c) as shown, smaller than the others and so only detectable at echo level 4. The resulting echo will be so brief in this case as hardly to show a variation in apparent depth. It will be seen that the trace to be expected from a single moving scatterer can be predicted when we know its appropriate "echo level for detection". This is of course dependent on its scattering cross section. It will also be noted that the diagram in Figure 9 calculated for a particular echo-sounder is a valuable indication of its properties as a fish detector—it is to be hoped that manufacturers of equipment will carry out the necessary tests, and publish such diagrams in the description of their equipments. (A difficulty may be variation from one installation to another).

The use of a narrow beam will clearly give information which is more easily interpreted, in that the depths of objects will be more clearly defined, and the thickness of a layer of objects will be relatively undistorted.

However, the use of a wider beam with a given transmitter power and receiver sensitivity will result in the recording of a greater number of echoes from effectively large targets, since the area of search is greater, but small targets will not be detectable to so great a depth.

Since ships are not in general steady on an even keel, results do not always follow the simple pattern indicated above, and there are, in fact, to be found on echo-traces many echoes represented by a single stroke of the stylus. Many of these are due to small targets picked up at a particular angle of the ship's roll, and we take it that no transmission has occurred again at that particular angle until the ship has passed clear of the target. Let us consider a practical case of an object in 60 m. depth of water, and an echo-sounder working at 30 r.p.m. on board a ship moving at 4 metres/second (about 8 knots). As a rough approximation our target might be detectable during the time the ship is moving through 20 metres (if the ship were on an even keel), i.e., for a period of 5 seconds. The period of roll of the ship might well be about 5 seconds, and the extent of the roll 20 degrees to either side. If the ship were on an even keel the expected number of echoes received is $2\frac{1}{2}$ but in the conditions stated it may be shown that the expected number falls below unity. It may be demonstrated that if targets are randomly distributed in the sea the number of single targets detected will be increased by the rolling, and the proportion of single stroke echoes will be greatly increased.

Before going on to consider distribution of targets, it is desirable to deal with three further factors which bear upon the pattern produced by a single target. The first two of these are pulse duration and supersonic frequency, and we here reproduce again the form of the pulse

finally applied to the recording paper (Figure 11).

It will be immediately obvious that the shorter the pulse length, the more will be the capacity of the echo-sounder to discriminate echoes from targets at slightly different distances. On 15 kc./s. machines the length "d" of the strong portion of the pulse is commonly about 2 milliseconds, giving a single stroke on the echo-sounder paper of about $1\frac{1}{2}$ metres depth (by the scale) on the shortest possible distinct mark. We have shown how this can vary. Clearly if we reduce the pulse duration to one-half of this, the echo resulting from a similar target will be only $^3/_4$ metre in extent. There may be an advantage in developing a shorter pulse duration, so long as the necessarily less sharp tuning of the receiver does not result in too much interference being picked up.

Alteration of the supersonic frequency of the echo-sounder affects operation in three ways. An increase in the frequency is expected to give more distinct echoes from smaller organisms and it is supposed that in this way a measure of the target size could be obtained by comparison of the echo amplitudes on two echo-sounders of different frequencies. This is based on the assumption that the targets do not have of themselves a natural resonance frequency within the range considered. If any such resonance existed and was at all sharp, it would be possible to provide an echo-sounder that would detect those particular targets to the exclusion of others.

Secondly, for a given supersonic frequency there is a minimum pulse duration practicable, and this corresponds to the duration of 10 to 20 cycles of this frequency. Attempts to reduce the pulse duration below this minimum result in greatly reduced transmission power, since full use cannot be made of the resonating properties of the oscillator. There is reduced sensitivity of the receiving oscillator for a corresponding reason, and there are difficulties in the design of the rectifying stage[1]) of the amplifier. All of these tend to reduce the signal/noise ratio of the equipment, i.e., its capacity to give clear representations. If we require pulses of short duration, therefore, we are forced to adopt high supersonic frequencies, and the limit is probably set by the onset of appreciable absorption by the water. Absorption by the plates of the ship, or the cover plate over the oscillator tank is also higher as frequencies increase, and is in fact the limiting factor in present British equipments.

Thirdly, as we have already shown, an increase in frequency makes possible the use of narrower "beams" of supersonic waves without making the oscillators too bulky. This brings with it the advantages and disadvantages discussed previously.

The final point to which we must give attention is the question of cross-noise, which is interference caused by the transmitter signal passing directly to the receiving oscillator. In bad cases, this effect makes the upper 5 to 10 m. of the echo-sounder recording useless for the detection of fish. With the adoption of higher frequencies and correspondingly shorter pulse duration, we would expect the transmitting oscillator to become quiescent more rapidly and thus reduce the extent of the cross-noise interference.

II. More than One Scattering Point.

(a) If two or more targets are present at distances from the oscillator which differ by more than half the pulse length in water (about $1\frac{1}{2}$ metres for 15 kc./s. equipments) the two targets will be recorded independently of one another.

(b) If two or three targets are present at ranges which differ by less than this, the echo amplitude will be indeterminate, since a certain amount of interference will occur between

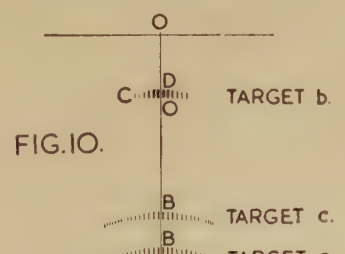


FIG. 10.

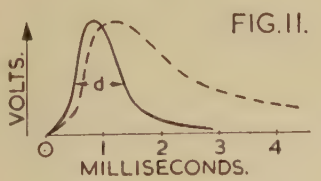


FIG. 11.

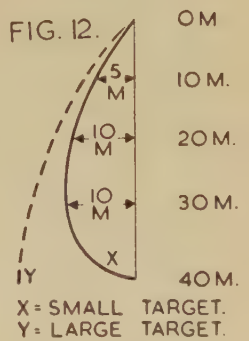


FIG. 12.

[1]) This does not apply to the fischlupe.

the reflected echoes. (We shall not expect any well defined diffraction pattern, since the pulse actually contains a range of frequencies extending in the case of a 15 kc./s. machine from about 13 to 17 kc./s. This is the inevitable mathematical consequence of transmitting in short pulses).

(c) If a number N (say, more than six) targets are present at ranges which differ by less than half the pulse length, they will give rise to a single echo of amplitude $\sqrt{N}$ times that from any one of the targets[1]). This assumes that none of the targets is shielded by the others.

Using the above information we proceed to deal with a few simple cases of arrangement of multiple targets.

The first case is that of a group of targets occupying a negligible area compared with that of the zone irradiated (e.g., if we are working at 60 m. as before, the zone irradiated will be a circle of about 20 m. diameter). If the group in question can be enclosed within a cube of approximately 3 m. in extent, the resultant trace will be of the typical half moon form derived for a single target. The length of the strokes in the pattern will be greater, but the curvature of the upper edge of the trace will be practically identical.

As the size of the patch increases, the half moon will be composed of progressively longer strokes, and the curvature of its upper edge becomes progressively less. Now the shape of the upper edge of the half moon for a single target is determined by known factors, viz:— the depth of water, the speed of the ship, and the depth scale and paper speed of the echo-sounder. It follows that if recordings are made in ideal smooth water conditions, and with the echo-sounder working at fairly high recurrence frequency (so that the half moons are well-defined) it is theoretically possible to obtain an estimate of the size of the group of targets. These matters are dealt with diagramatically in the Supplementary Note, p. 45.

If the closely-spaced group of targets considered above becomes greater in extent it will be represented eventually as a layer with a sharply defined upper surface and a poorly defined lower one, of apparent depth dependent on (a) the depth of the water layer actually occupied by targets, and (b) the effective angle of the echometer beam.

We now pass to the effects to be expected from individual targets spaced at appreciable distances apart. Consideration of the shape of the zone of detection shows that coalescence into a single trace will occur at some horizontal spacing which increases with the depth, and that the permissible spacing continues to increase up to a greater depth for large targets than for small (Figure 12).

It has been shown experimentally (von Brandt & Schärfe, 1950) that, as an example, a set of dummies $2\frac{1}{2}$ metres apart gave the appearance of a continuous shoal at a depth of 23 m. It will be clear in the application of this to fish identification (Schüler & Krefft, 1951) that a particular shoaling pattern which gives rise to a banded or disjointed pattern when detected in the upper water layers, might well give rise to a continuous trace if detected at greater depth.

Future Research.

It will be clear that the probable developments of the deductive method will follow the line of filling in the many gaps, which will probably have been obvious. First, we have not available in general the Polar Diagrams of the echo-sounders we use. Second, we have not the information on the effectiveness of natural targets as scatterers which would enable us to allot them their appropriate "level for detection" in the irradiated zone. Third, we have no information on the relative efficiency of different supersonic frequencies as detectors, or on any resonances that exist in natural targets. Finally, existing echo-sounders (except the fischlupe) give very little precision in the estimation of echo amplitude.

These remarks close the discussion of the deductive method of attack. While progress will continue, we are unlikely to get all the answers by this approach. The fact that ships are seldom steady, and that shoals of fish in the sea are not necessarily homogeneous makes exact evaluation of traces a problem to which no final answer seems close at hand, and to solve which will require the blending of work at sea with quantitative experiments ashore.

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[1]) This is due to the fact that N targets reflect N times as much *energy* as one target. The *intensity* of the echo is thus increased by the factor N and so its amplitude is by a factor $\sqrt{N}$.

THE INDUCTIVE METHOD

We have now to review the available information and results of the first method of attack, described in principle in the introduction, remembering that the factors affecting the character of fish echoes are (a) scattering efficiency per fish, (b) density of fish concentration, (c) shoaling pattern, (d) depth at which the fish are detected.

I have already mentioned the work of Skipper Ronald Balls and make no apology for emphasizing again the significance of this as the great pioneer effort.

Asdic.

Later work has been devoted to assessment of Asdic and more intensively in most countries to the assessment of modern recording echo-sounders for fish finding. The earliest experiments with Asdic were made immediately after the war by Dr. Henry Wood of this laboratory, accompanied by Dr. W. C. Hodgson of Lowestoft (Anon., 1949). In these trials naval vessels were used by the courtesy of the British Admiralty. These experiments were quite successful, but the high cost of the equipment made it then, as now, seem unlikely to be economic to equip local fishing vessels in this way. There remained the possibility of special search vessels being employed, but it was not obvious that this would be profitable in local conditions.

That a search vessel so equipped can in some areas be of tremendous value has been convincingly shown by the recent Norwegian work (Renou, 1951; Devold, 1951; Cushing *et al.*, 1952) in opening up an oceanic fat herring fishery in the Norwegian Sea. It is beginning to be realized that a search vessel can be an economic proposition if worked in conjunction with any large fleet of fishing vessels. This is likely to be true even where the search is made with a normal echo-sounder only; but once such a search vessel is supplied for any fleet it immediately becomes desirable and economic to provide all possible means of search and the use of Asdic, or other forms of horizontal acoustic fish finder, becomes highly desirable if only as a supplement to the normal machine.

Experiments carried out in the first half of 1953 from Aberdeen, using Asdic on the fishery protection vessel H. M. S. "Welcome", in collaboration with the echo-sounders on the research ship "Clupea", have confirmed this view. In the light of these and other experiments the writer has surveyed some of the possibilities recently (Craig, 1953), suggesting the value of developing a much lighter and more compact horizontal sounder than Asdic. A fish finder such as this might well prove to be important to the further development of pelagic fishing, particularly pelagic trawling, in conjunction of course with the best means of vertical sounding. It was further suggested that more convenient measurement of bearing could be obtained by the use of split-beam techniques, though there would undoubtedly be difficulties to overcome in the design of such equipment.

Identification of Traces.

Fish finding and identification with the conventional echo-sounder has been dealt with very completely by Hodgson (1950) in a paper illustrated by many photographs of traces obtained with British echo-sounders, mainly of the type manufactured by Messrs. Kelvin and Hughes. The causes of these traces have been identified by him and other English workers as pilchard, herring, sprat, mackerel, gadoid fish and (with less certainty), larval fish (Hodgson, 1950; Burd & Lee, 1951; Parrish & Craig, 1951). The identification of these was achieved by the use of the ring-net, suitable types of handlines and, in the latter case, plankton nets.

Dr. Hodgson is to be congratulated on placing such a large body of information in the hands of fishermen in English waters, to which the identifications apply. His paper is the only comprehensive survey in existence, and those who have been engaged in similar work appreciate how much painstaking effort must have been required to gather the information.

It is evident from these results, however, and those of other workers, that the appearance on the echo-sounder record of fish such as herring can vary considerably from place to place and from time to time. Clearly the form of a particular trace will vary according to the depth of the shoal, its constitution and the relative speed of shoal and vessel. One gets the impression for example that sprat and mackerel traces are very similar in general appearance, and that larval fish traces are

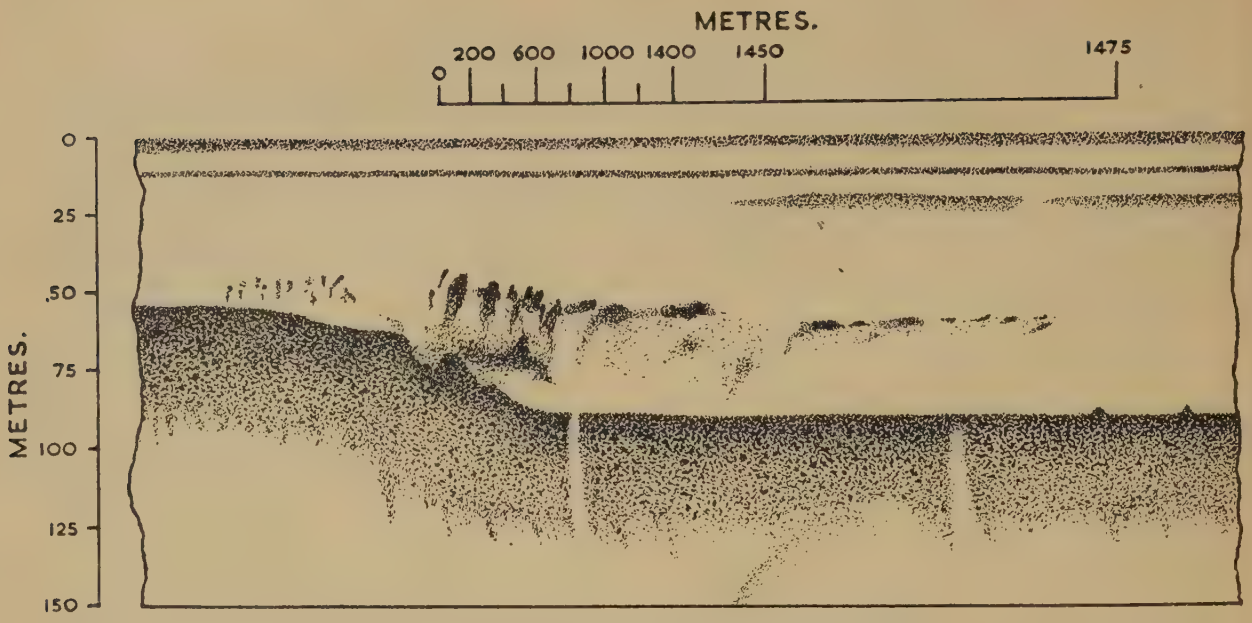


Figure 13. Example of an echo-trace with a horizontal scale added to indicate ship's movement.

liable to be misleading if they are not distinguished as such.

We note (HODGSON's Figure 12) the association of comet-like formations with sprats. The reason for the formation of "comets" is well known, and they can be produced by any small concentrated shoal of fish. The so-called sickle-shaped trace, which would appear to be a comet on a different lateral[1]) scale is attributed to pilchard. Yet the "sickle" (a stronger echo than the "comet" as defined by HODGSON) is also a common form; it is easily recognized in areas not frequented by the pilchard, and is there usually attributed to herring. The opinion of German scientists (GABLER, 1950; SCHUBERT, 1950; SCHÜLER & KREFFT, 1951) that these results are not of universal application will probably be shared by most workers now. *Local knowledge is still required for intelligent interpretation of traces* and it is to be doubted whether rules of universal application are likely to be deduced in the near future. An example of the difficulties involved arises from the common association of whiting and herring in Scottish waters. When the whiting adopts a pelagic existence it produces traces which cannot easily be distinguished from those made by herring. It is hoped that new techniques, of studying the reaction to light, may be of value in distinguishing these species.

We can at the moment speak of fish traces from large or small shoals of pelagic fish, and scattering layers—fainter traces of great extent—whose composition is not settled, though identifications have been suggested in a few instances (BURD & LEE, 1951; TROUT *et al.*, 1952). We speak of a scattering layer when small organisms such as larval fish or planktonic forms are presumed to be the cause, and the trace satisfies the conditions mentioned. It is probably worth mentioning that in shallow water, say, up to 30 m. in depth, it is possible to obtain relatively good definition since the speed of rotation of the sounder can be high. This high quality of definition has to be sacrificed in deeper water since it is always desirable to have the whole depth under observation in any fishing survey.

It is, in the writer's opinion, very bad practice to use a high-speed sounder in deep water. This could be done, for instance, with some Kelvin-Hughes sounders, where the whole depth can be examined on either a deep scale, or section by section using the shallow scale and the phasing control (i.e., a scale such as 60 to 80 fathoms). If the latter is done, then valuable information may be

[1]) The writer suggests that it would be very helpful if reproductions of echo-traces could always carry on them a horizontal as well as a vertical scale. An example is given in Figure 13.

missed, and more important, repeated echoes of the sea-bed may appear and cause confusion.

The best practice with a recording sounder is either to use a scale which will search the whole depth from surface to bottom, or in oceanic conditions to use a scale of 0—200 fathoms or thereby. It may be mentioned that the difficulty of repeated echoes from the sea bed does not arise with the 15 m. expanded scale of the fischlupe. The magnified scale achieved in this case does not involve increasing the number of transmissions per minute.

The writer's view is then that the echo-sounder will undoubtedly show up fish and sometimes smaller organisms, but that identification depends at present largely on local knowledge, which should be as detailed as possible. In the meantime all means of differentiating traces are being studied in the hope that some measure of identification by appearance and reaction to stimulus may become possible and that rules, even if strictly local in their application, may be formulated for this purpose.

The work being done falls into two categories. The first is a comparison of routine echo-surveys with catch data. Descriptions of this type of work have been published for an English fishery by Cushing (1952) and for a Scottish one by Parrish (1952), and this work continues intensively.

Use of Explosives and Photography.

The second approach is sampling on the spot and tests of various kinds. Sampling by net and line has already been mentioned, and is of course used whenever possible. However, in shallow water down to about 20 m., the use of a small explosive charge has been found to be invaluable (Craig, 1952). In the Scottish work charges of $\frac{1}{2}$ lb. of blasting gelatine, fired electrically, have been found satisfactory and have provided convenient samples for analysis.

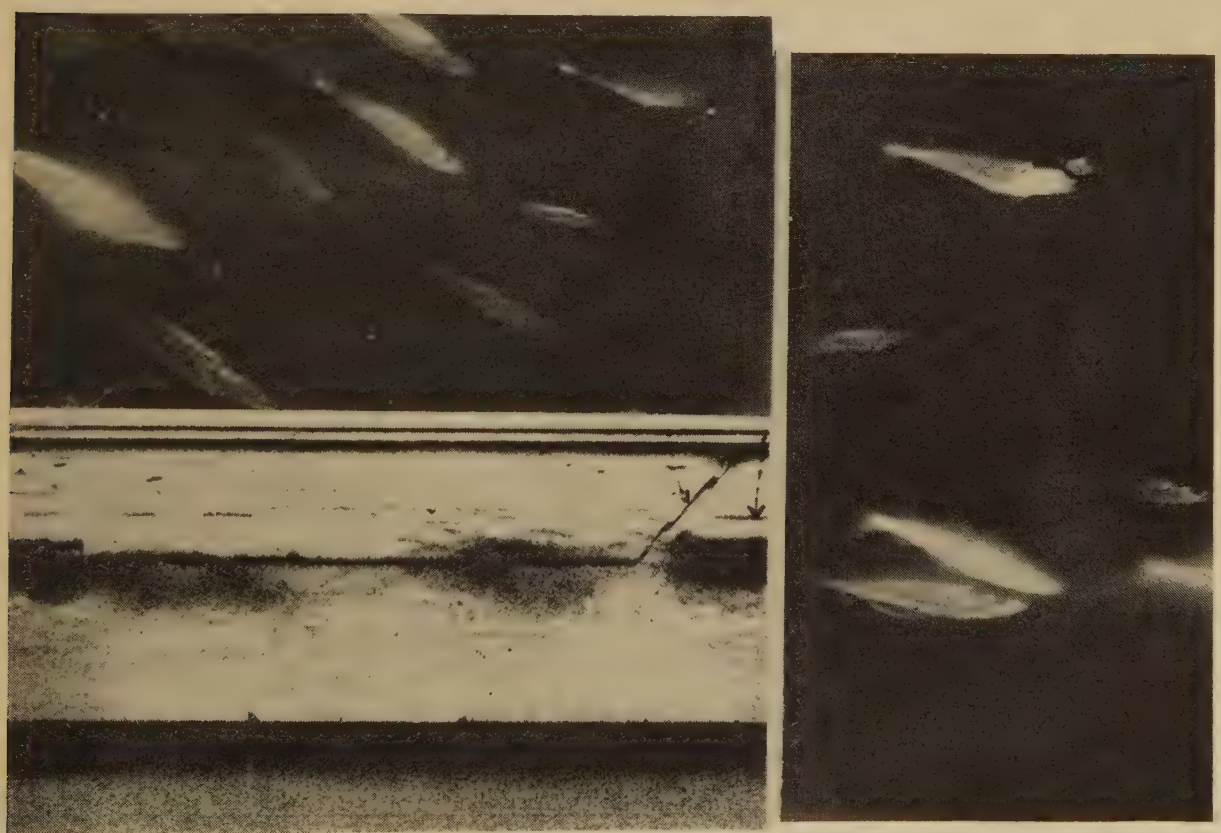


Figure 14. Echo-traces produced by whiting gathered under a lamp, and underwater photographs taken in the traces.

Photography is a useful technique where dense concentrations are found, but is a relatively slow and difficult one. The Robot camera described by the writer to the Council in 1952 has been used for this purpose with some success but it is surprising how many blanks are obtained even in a trace of some density. Continued use of the camera may be expected in the course of time to give some information about shoaling patterns and density of fish, and detailed information about plankton layering. It should be emphasized that a flash technique is *essential* as the use of a fixed light grossly modifies normal behaviour patterns. Particularly during daylight it is to be feared that even the presence of the camera may frighten fish and make it difficult to obtain "natural" photographs. In Figure 14 is shown a photograph of whiting and the echo-trace produced by them. Of twenty-one exposures, five showed recognizable whiting, and none showed any other type of fish. Since explosive sampling provided a mixture of whiting and young herring in almost equal numbers it seems safe to infer that the dark heavy trace is produced by the whiting, and the scattered marks above by the herring.

This trace was obtained with the ship at anchor in deep water (37 fathoms) and the heavy aggregation of fish was produced by an underwater light. This brings us to our next point.

Use of Underwater Lights.

Reports have been made (Parrish & Craig, 1951; Craig & Baxter, 1952; Hodgson & Richardson, 1949; Richardson, 1952) of distinct and characteristic reactions of echo-traces at night to an underwater lamp. These early reports were tentative in their interpretations, but they make it perfectly plain that unmistakeable differences in behaviour exist between various organisms, and that in favourable circumstances these differences can be used as an aid in the interpretation of echo-traces. Much more work on these lines has already been carried out and more will be required before good generalizations can be made. However, in certain areas, such as the west coast of Scotland, it would seem that an underwater lamp is an adjunct of real value.

The Reaction of Fish to Echo-Sounder Pulses.

Such information as is available (Schubert, 1950; Krefft & Schüler, 1951 a, 1951 c; Schärfe, 1951), suggests that fish are completely insensitive to the supersonic pulses from modern echo-sounders. Marked flight reactions have been observed, however (Kreff & Schüler, 1951 a) to the note of a sonic sounder (3 kc./s.) and to sharp audible sounds.

CONCLUSION

The economic value of the echo-sounder search is established, even though the identification of traces is still in its infancy. (After all, if fishing were guided only by the consideration that some organisms are under the ship, it would at least be gaining by that consideration, and it has been shown that we can even now go further than that). Modern echo-sounders have a long way to go, and design has only very recently been influenced by the fish-finding application. It may be that by the use of much higher supersonic frequencies and much briefer pulses (Schüler, 1951; Schüler & Krefft, 1951) we can approach the ideal of "one mark—one fish" and begin to seek out both the pelagic and the demersal fish with precision. Manufacturers should also bear in mind the negative criterion of perfection, and strive with all possible means to that machine about which we can also say with confidence "no mark—no fish"!

Supplementary Note.

The shapes of the echo-traces from certain simple arrangements of targets are as follows:—

(1) Figures 15 and 16 show the curve of the top of the trace to be expected from a single target below the ship's course, and 20 m. to one side of it respectively. The target is taken to be at 60 m. and arbitrary echo-sounder scales have been assumed. Clearly in the first case the apparent depth is given by $d^1 = \sqrt{d^2 + s^2}$ where d is the true depth and s the horizontal distance in the direction of the ship's course from the oscillators to the target. According to the size of the target, more or less of the curve will, of course, appear in a practical case. In the second case $d^1 = \sqrt{d^2 + s^2 + 20^2}$, i.e. the curve will be identical to that from a target on the course but, at a depth ($\sqrt{d^2 + 20^2}$) equal to the minimum distance of this target from the oscillators. When we have made allowance, if necessary, for the curvilinear system of recording commonly used, we see that for a given minimum apparent depth, any single target, however placed, gives rise to the same shape of curve. The thickness of the curve traced out on the paper will in this case depend only on the pulse duration and will be greater at the centre of the "comet" since the echoes are stronger there.

(2) Figure 17 shows the form of echo-trace to be expected for groups of targets, respectively 10 m. and 20 m. in extent, confined entirely to the exact depth of 60 m. The dotted lines indicate the shape of the lower edge of the echo if the pulse shape were of infinitesimal length. To the bottom of this echo, therefore, we have to add a thickness due to the pulse duration, which as before is greater at the centre of the comet. It will be obvious that the zones A and B of these echoes will, in fact, be normally lost before the lines at C and D, as they are due to targets at a greater angle from the vertical than these latter.

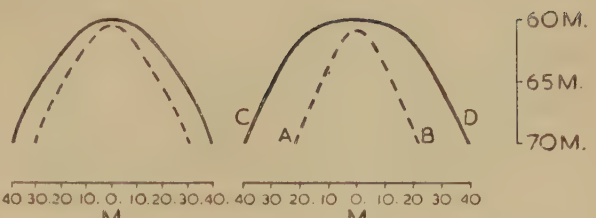
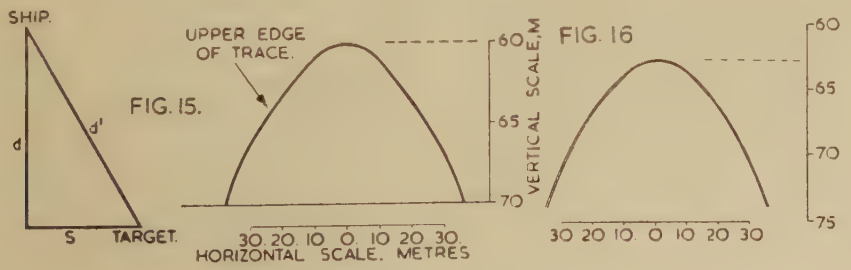


FIG. 17.

If the targets be distributed in depth also, we are near enough to the truth if we add below these traces shading corresponding to the depth of the distribution.

The point we wish to make here is that echo-traces from groups of targets of horizontal extent less than about $\frac{1}{3}$ the depth of water will give rise to echoes which in the ideal cases examined have a flat top of extent equal to the width of the target, but which in practice will be similar to single target echoes with apparently less curvature at the top. We note also that this apparent difference in curvature could be due to a small shoal swimming in the same direction as the ship (Schüler, 1951), and thus reducing the relative speed.

(3) In the case of targets of horizontal extent comparable with the depth of water or greater, it seems only necessary to observe that the flattening of the echo should be sufficiently obvious, and as the target extends further we soon pass over to the common layer appearance, on which the only comment worth making is that most echo-sounders give but a poor estimate of the depth of the lowest targets.



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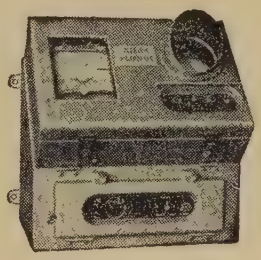

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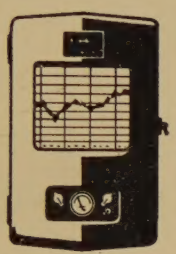

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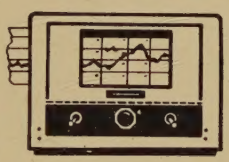

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